ESD-TR-69-374

MEASUREMENTS OF METEOROLOGICAL PARAMETERS AND RADIO REFRACTIVITY IN THE CARIBBEAN

L. G. Rowlandson
R. J. Aldrich
J. R. Herlihy

November 1969

AEROSPACE INSTRUMENTATION PROGRAM OFFICE
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

(Prepared under Contract No. F19628-69-C-0208 by Syracuse University Research Corporation, Merrill Lane, University Heights, Syracuse, New York.)

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FOREWORD

This report is prepared for the

Aerospace Instrumentation Program Office
Electronic Systems Division
Air Force Systems Command of the United States Air Force
Bedford, Massachusetts

Air Force Program Monitor - Lt. C. Schafer, ESD/ESSIE

Project Number 6684, Task 6684.08

covering research over the period

1969 March 1 to 1969 November 10.

Prepared under Contract No. F19628-69-C-0208 by

Syracuse University Research Corporation
Merrill Lane, University Heights
Syracuse, New York

This report was reviewed and approved.

C. Schafer, Lieutenant, USAF
Program Manager for ESD/ESSIE/6684.

ABSTRACT

A series of meteorological measurements was made in the northern part of the Caribbean Sea during the spring of 1969, to characterize the Trade Wind Inversion and its effect on radio wave propagation. Among the measurements made were data collected from the sensors on the airborne platform of the USAF C-131 Convair (37812), which was provided for use on this contract. This report is a compendium of some of the airborne data, namely of the processed digital records of air temperature, air pressure, refractivity, water vapor pressure and potential temperature. These values are presented as absolute quantities which have been corrected to compensate for the effect of aircraft motion and thermal expansion of the microwave refractometer sensing cavity.

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SECTION I

INTRODUCTION

The Trade Wind Inversion produces conditions for the formation of an elevated layer. The moist marine atmosphere below the layer and the dry air above the layer, which is produced by subsidence, come together around one to two kilometers above sea level. The rapid decrease of water vapor pressure with height over this interface causes a corresponding decrease in radio refractivity. Such a layer not only acts as a partial reflector for radio waves but can also bend radio signals earthward with enough intensity to create a guide for signals to propagate beyond the normal radio horizon.

The detailed characteristics of these layers in terms of their thickness, height, refractivity gradient and spatial extent define their effect on radio signal propagation. Using an instrumented C-131 Convair (USAF 37812) measurements of meteorological and radio refractivity parameters were made over an extended area of the northern part of the Caribbean Sea. This instrumentation is described in the Appendix.

The variation of meteorological and refractivity parameters with height is presented herein and the maps associated with these profiles defines the locations where measurements were made. The data used to generate these profiles were originally recorded on the aircraft in digital format on punched paper tape. These data were then processed with a computer program wherein corrections were applied to compensate for the dynamic effects of the aircraft motion. As shown in Section II, other meteorological parameters such as the vapor pressure, e, and the potential air temperature, θ, were derived from directly measured parameters.

Some measurements are missing due to the malfunction of the pressure instrument during the first part of Mission 3. Also, the first paper tape recordings during Mission 13 were unusable due to a mechanical breakdown of the paper tape speed control unit. These latter records were recorded on magnetic tape and are available in Technical Report I[3].

SECTION II

THE DERIVATION OF ABSOLUTE METEOROLOGICAL AND REFRACTIVITY PARAMETERS AND THEIR ACCURACIES

The radio refractivity, N, is related to meteorological parameters by the equation[1]

$$N = \frac{77.6\,P}{T} + \frac{3.73 \times 10^5\, e}{T^2} \qquad (1)$$

where P = the air pressure (millibars).
T = the air temperature (degrees Kelvin).
e = the water vapor pressure (millibars).

The variation in refractivity, N, with height is measured directly with a Crain microwave refractometer[2]. Also, the air pressure, P, and air temperature, T, are directly determined, thereby giving a method to calculate the vapor pressure, e.

Several errors enter into these calculations. In the first place the Crain refractometer responds very rapidly to changes of refractivity, N, within the sensing cavity. However, it is difficult to use as an absolute recording instrument. The physical size of the sensing cavity increases with air temperature thereby causing an error in the measurement of the resonant frequency of the cavity. This effect can change in magnitude depending upon aging and the degree of contamination within the cavity. From laboratory tests one attempts to determine the change in resonant frequency per degree Centigrade. This coefficient is then used with air temperature measurements to compensate for the effect of the expansion or contraction of the cavity on the measurements of N.

A second error is involved with relating the indicated refractivity from the refractometer with meteorological conditions. This relationship can be attempted by recording from the refractometer with the aircraft on the ground and relating these recordings with psychometric measurements also obtained in proximity to the aircraft. Errors in relating the two sets of data can occur because of moisture condensation in the refractometer cavity. A better method to avoid the possibility of condensation is to relate the refractometer data with radiosonde data when the aircraft is in flight. This calibration method requires that the aircraft be in the correct position at the right time when the radiosonde is released. This latter calibration procedure usually requires that special radiosonde launches be carried out and there is good coordination between the aircraft commander and the launch personnel.

The air pressure, P, and air temperature, T, can be very accurately measured. The air pressure is recorded from a static port in the aircraft skin which was designed to essentially eliminate the pressure errors due to aircraft motion. The MKS pressure recorder (see Appendix) is a laboratory calibrated instrument with an absolute accuracy of about 0.3 millibars.

The effect of aircraft motion on the temperature probes is to increase their indicated temperature because of increased air pressure around the temperature element. This error is generally proportional to the square of the indicated aircraft velocity. Calibration flights were carried out to determine the magnitude of these effects on the three temperature probes. The vortex thermometer attempts to compensate for the raw pressure effect by causing the air to swirl at high velocity around the temperature element. By introducing this increased tangential velocity the air pressure decreases, as does the air temperature, thereby compensating for the effect of aircraft motion. By using the vortex temperature probe the corrected air temperature can be found to within one degree centigrade.

The potential air temperature, θ, is given by

$$\theta = T \left(\frac{P}{1000}\right)^{-K} \tag{2}$$

where $K = R/C_p$ (3)

and R = the specific gas constant for air.
C_p = the specific heat capacity for air at constant pressure.

and $K = 0.286$ for dry air.

The potential air temperature, θ, and the air temperature, T, are presented in degrees centigrade on the profiles rather than in degrees absolute (degrees Kelvin) as they are used in the equations. Under adiabatic conditions the potential temperature, θ, of a parcel of air will be constant with height. It will be seen on most profiles that the potential temperature, θ, increases rapidly at the altitude where the Trade Wind Inversion forms. This is simply due to the fact that heating associated with the pressure increase in subsiding air has modified the normal adiabatic conditions. This rapid increase in potential temperature also means that the great stability is produced and vertical air motion is constrained. The moist marine layer is then held under the inversion.

In summary, the largest errors are due to the inability to associate refractometer records of N with an independent and accurate standard.

Although relative changes in N over the profile can be maintained, after correction of the data, to within one unit, the absolute accuracy can be from five to ten N units in error. In the calculation of vapor pressure, e, this leads to errors from one to two millibars around one kilometer in altitude. The vapor pressure may, therefore, show a negative value which, of course, is not possible in reality.

For investigation of the effect of refractivity structure on radio wave propagation, accurate relative information is far more important than precise absolute accuracy. Therefore, the enclosed data plots are very meaningful for the particular analysis to be undertaken.

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1. Smith, E. K., and S. Weintraub (August 1953), "The Constants in the Equation for Atmospheric Refractive Index at Radio Frequencies," Proc. IRE, 41, pp 1035-1037.

2. Crain, C. M. (May 1950), "Apparatus for Recording Fluctuations in the Refractive Index of the Atmosphere at 3.2 Centimeter Wavelengths," Rev. Sci. Instr., 21, No. 5, pp 456-457.

3. Aldrich, R. J., Herlihy, J. R. and L. G. Rowlandson (August 1969), "Caribbean Upper Air Measurements, Technical Report I of Caribbean Radio Ducting Investigations," ESD-TR-69-366.

SECTION III

COMPENDIUM OF AIRCRAFT AND GEOGRAPHICAL DATA


MASTER FLIGHT RECORD
UNITED STATES
ATLANTIC OCEAN
GULF OF MEXICO
MOBILE
EGLIN AFB
PATRICK AFB
PATH II
PATH III
PATH VIII
KEY WEST NAS
PATH I
NASSAU
BAHAMA ISLANDS
PATH XIII
GRAND TURK ISLAND
HAVANA
CUBA
MERIDA
MEXICO
GEORGETOWN
CAYMAN ISLANDS
PATH IX
GREATER ANTILLES
JAMAICA
KINGSTON
DOMINICAN REPUBLIC
HAITI
PATH XI
RAMEY AFB
SAN JUAN
PUERTO RICO
PATH X
LESSER ANTILLES
BRITISH HONDURAS
CARIBBEAN SEA
GUATEMALA
HONDURAS
EL SALVADOR
NICARAGUA
COSTA RICA
PANAMA
COLUMBIA
VENEZUELA
GULF OF MEXICO – CARIBBEAN AREA
SCALE 1:5,702,400 OR 90 MILES TO 1 INCH
STATUTE MILES
KILOMETERS
TRACED FROM NATIONAL GEOGRAPHIC SOCIETY MAP, WASHINGTON, DECEMBER 1939

TABLE I
FLIGHT LOG

Mission No.	Spiral No.	Path	Location	Up or Down	Spiral Start Time
1 (6 March)	A	I	a. Key West NAS	↑ 10K 500	1131 Z
	B	I	b. 24-06 N 81-51 W	↓ 10K 500	1214 Z
	C	I	c. 24-06 N 81-08 W	↓ 15K 500	1315 Z
2 (6 March)	A	I	c. 24-06 N 81-08 W	↓ 10K 500	2019 Z
	B	I	a. Key West NAS	↓ 10K 500	2107 Z
	C	I	b. 24-06 N 81-51 W	↓ 10K 500	2156 Z
	D	I	c. 24-06 N 81-08 W	↓ 10K 500	2235 Z
	E	I	a. Key West NAS	↑ 10K 1K	2313 Z
3 (9 March)	A	II	a. Key West NAS	↑ 10K 500	1555 Z
	B	II	b. 25-15 N 83-15 W	↓ 10K 500	1635 Z
	C	II	c. 26-00 N 85-00 W	↓ 10K 500	1743 Z
	D	II	d. 27-07 N 86-20 W	↓ 10K 500	1834 Z
	E	II	e. 29-10 N 89-07 W	↓ 10K 500	2016 Z
4 (10 March)	A	III	a. 29-00 N 87-00 W	↓ 10K 500	2132 Z
	B	III	b. 25-00 N 88-13 W	↓ 10K 500	2217 Z
	C	III	c. 23-00 N 89-00 W	↓ 10K 500	2313 Z

TABLE 1 (Cont'd.)
FLIGHT LOG

Mission No.	Spiral No.	Path	Location	Up or Down	Spiral Start Time
5 (11 March)	A	IV	a. 20-00 N 86-25 W	↓ 11K 500	1848 Z
	B	IV	b. 19-00 N 85-35 W	↓ 11K 500	1935 Z
	C	IV	c. 18-30 N 84-00 W	↓ 11K 500	2030 Z
	D	IV	d. 19-15 N 81-15 W	↓ 11K 500	2150 Z
6 (14 March)	A	V	a. 18-36 N 62-00 W	↑ 10K 500	1629 Z
	B	V	b. 17-30 N 67-00 W	↓ 10K 500	1706 Z
	C	V	c. 16-17 N 67-17 W	↓ 10K 500	1810 Z
	D	V	d. 15-37 N 67-23 W	↓ 10K 500	1848 Z
	E	V	e. 17-03 N 66-14 W	↓ 10K 500	1945 Z
	F	V	f. 18-23 N 65-37 W	↓ 10K 500	2033 Z
7 (17 March)	A	VI	a. 18-32 N 67-07 W	↑ 10K 500	1702 Z
	B	VI	b. 19-10 N 68-01 W	↓ 10K 500	1744 Z
	C	VI	c. 19-53 N 69-00 W	↓ 10K 500	1828 Z
	D	VI	d. 20-36 N 70-00 W	↓ 10K 500	1915 Z
	E	VI	e. 20-34 N 71-10 W	↓ 10K 500	1955 Z
	F	VI	f. Grand Turk	↓ 10K 500	2033 Z

TABLE 1 (Cont'd.)
FLIGHT LOG

Mission No.	Spiral No.	Path	Location	Up or Down	Spiral Start Time
8 (18 March)	A	VII	a. Grand Turk	↑10.5K 500	1447 Z
	B	VII	b. 22-35 N 73.07 W	↓10.5K 500	1547 Z
	C	VII	c. 23-08 N 74-00 W	↓10.5K 500	1630 Z
	D	VII	d. 24-00 N 75-35 W	↓10.5K 500	1723 Z
9 (21 March)	A	I	a. Key West NAS	↑10K 500	1135 Z
	B	I	b. 24-06 N 81-51 W	↓10K 500	1200 Z
	C	I	c. 24-06 N 81-08 W	↓10K 500	1235 Z
10 (21 March)	A	I	b. 24-06 N 81-51 W	↓10K 500	1608 Z
	B	I	c. 24-06 N 81-08 W	↓10K 500	1645 Z
	C	I	a. Key West NAS	↓10K 500	1720 Z
11 (21 March)	A	I	b. 24-06 N 81-51 W	↓10K 500	2159 Z
	B	I	c. 24-06 N 81-08 W	↓10K 500	2233 Z
	C	I	a. Key West NAS	↑10K 500	2318 Z
12 (23 March)	A	VIII	a. Key West NAS	↑10K 500	0712 Z
	B	VIII	b. 24-35 N 82-37 W	↓10K 500	0748 Z
	C	VIII	c. 24-35 N 83-32 W	↓10K 500	0828 Z
	D	VIII	d. 24-35 N 84-26 W	↓10K 500	0909 Z
	E	VIII	e. 24-35 N 83-03 W	↓10K 500	0952 Z

TABLE 1 (Cont'd.)
FLIGHT LOG

Mission No.	Spiral No.	Path	Location	Up or Down	Spiral Start Time
12 (23 March)	F	VIII	f. 24-43 N 81-04 W	↓ 10K 500	1043 Z
	G	VIII	a. Key West NAS	↓ 10K 500	1119 Z
13 (24 March)	A	VIII	a. Key West NAS	↑ 10K 500	1132 Z
	B	VIII	b. 24-35 N 82-37 W	↓ 10K 500	1212 Z
	C	VIII	c. 24-35 N 83-32 W	↓ 10K 500	1257 Z
	D	VIII	d. 24-35 N 84-26 W	↓ 10K 500	1348 Z
	E	VIII	e. 24-35 N 83-03 W	↓ 10K 500	1430 Z
	F	VIII	a. Key West NAS	↓ 10K 500	1511 Z
14 (25 March)	A	VIII	a. Key West NAS	↑ 10K 500	1154 Z
	B	VIII	b. 24-35 N 82-37 W	↓ 10K 500	1238 Z
	C	VIII	c. 24-35 N 83-32 W	↓ 10K 500	1370 Z
	D	VIII	d. 24-35 N 84-26 W	↓ 10K 500	1403 Z
	E	VIII	e. 24-35 N 83-03 W	↓ 10K 500	1444 Z
	F	VIII	a. Key West NAS	↓ 10K 500	1527 Z

MISSION NO. 1

Date: 6 March 1969

The aircraft was flown from Key West Naval Air Station in a generally eastward direction on the flight path designated I on the Master Flight Record Map. The extent of the reach eastward was approximately 110 statute miles.

Data were obtained during three spirals flown from altitudes of 500 to 10,000 feet (approximately 0.15 to 3.0 km). The spirals were located as shown on the Master Flight Map at

Spiral	Location	Spiral Start Time Z	Local
A	a. Key West NAS	1131	0631
B	b. 25-06 N, 81-51 W	1214	0714
Climb 1			
C	c. 24-06 N, 81-08 W	1315	0815

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SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300

STATUTE MILES

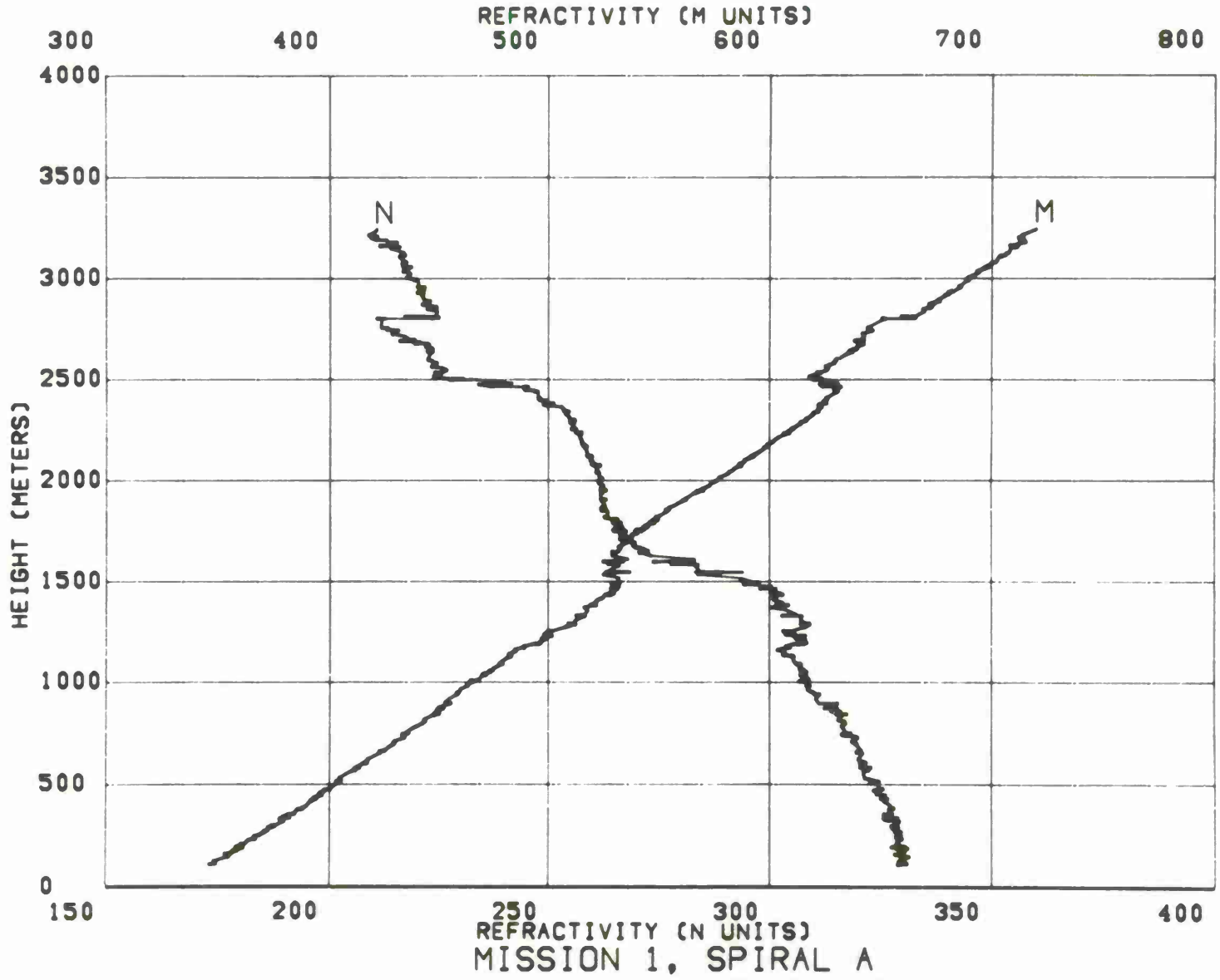
100 50 0 100 200 300 400

KILOMETERS

FLIGHT PATH I

MISSIONS 1 AND 2 — 6 MARCH 1969

MISSIONS 9, 10, AND 11 — 21 MARCH 1969



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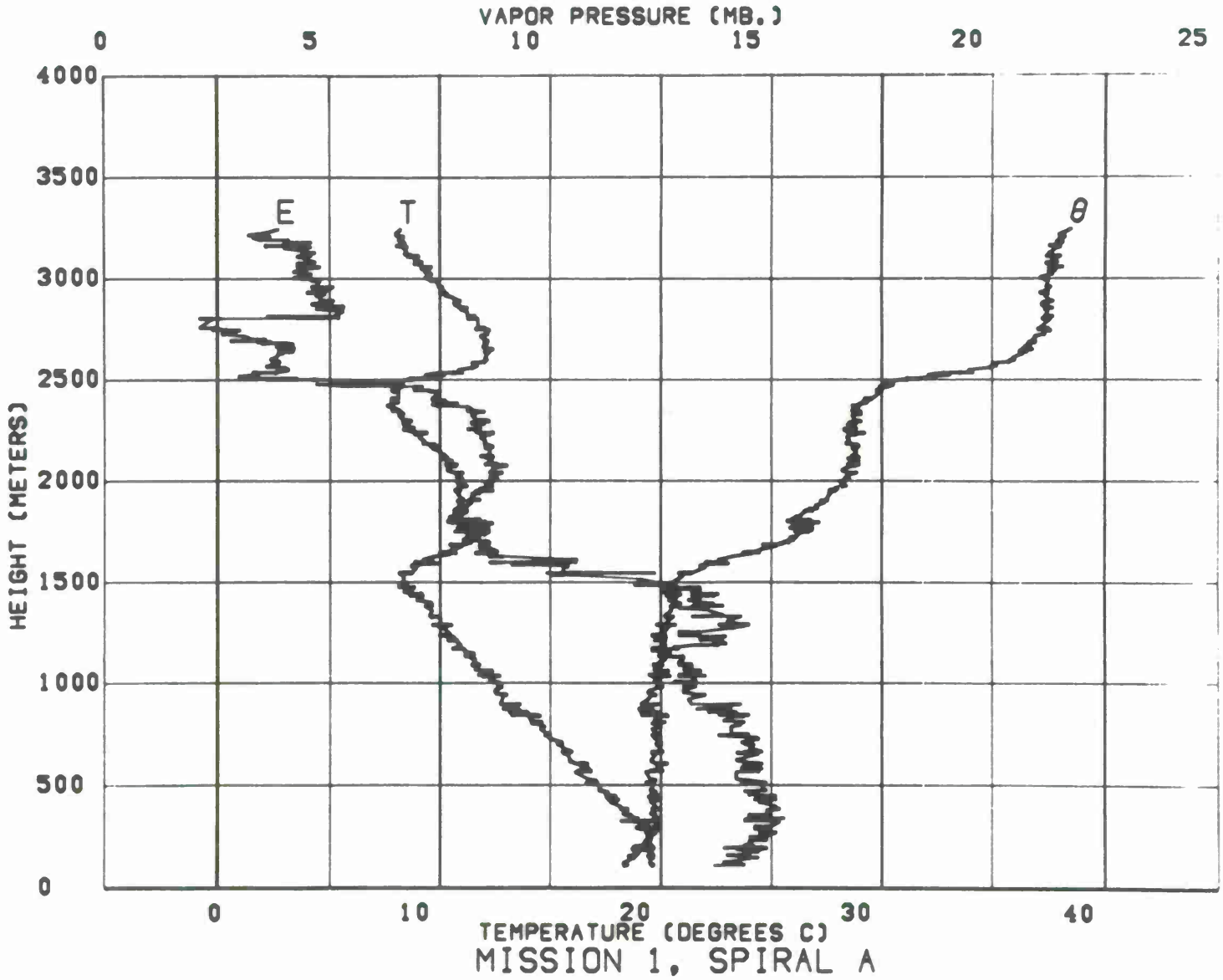

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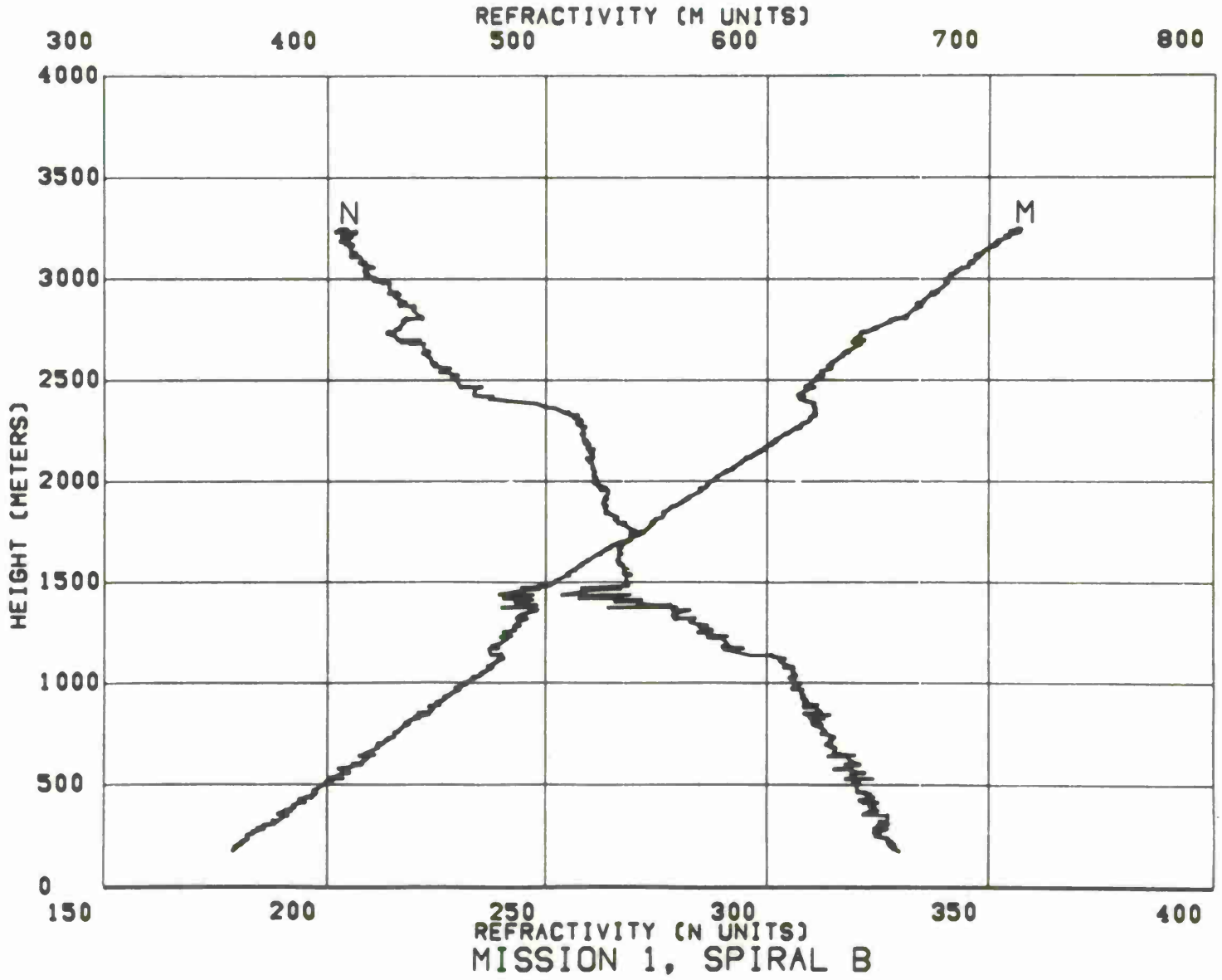

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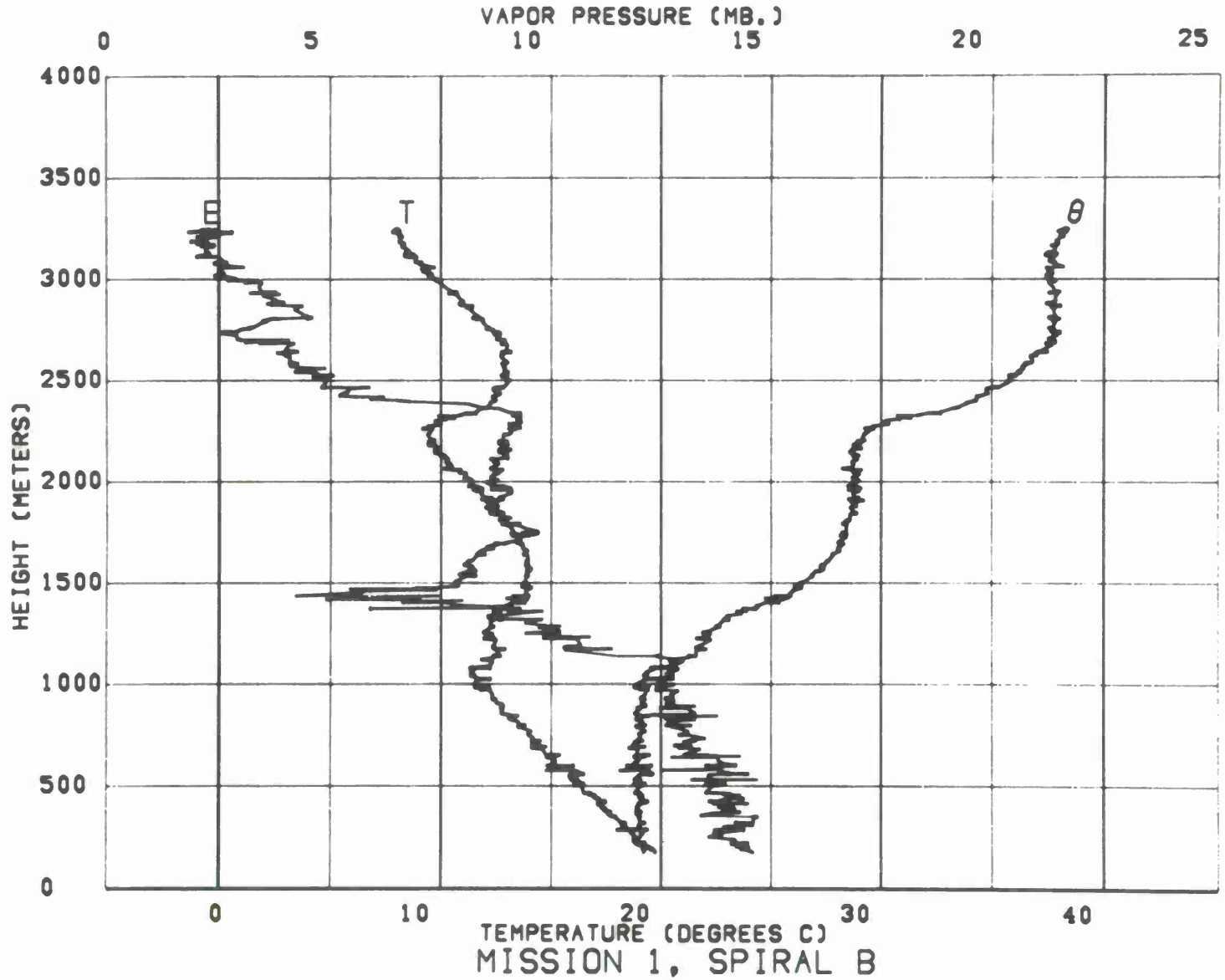

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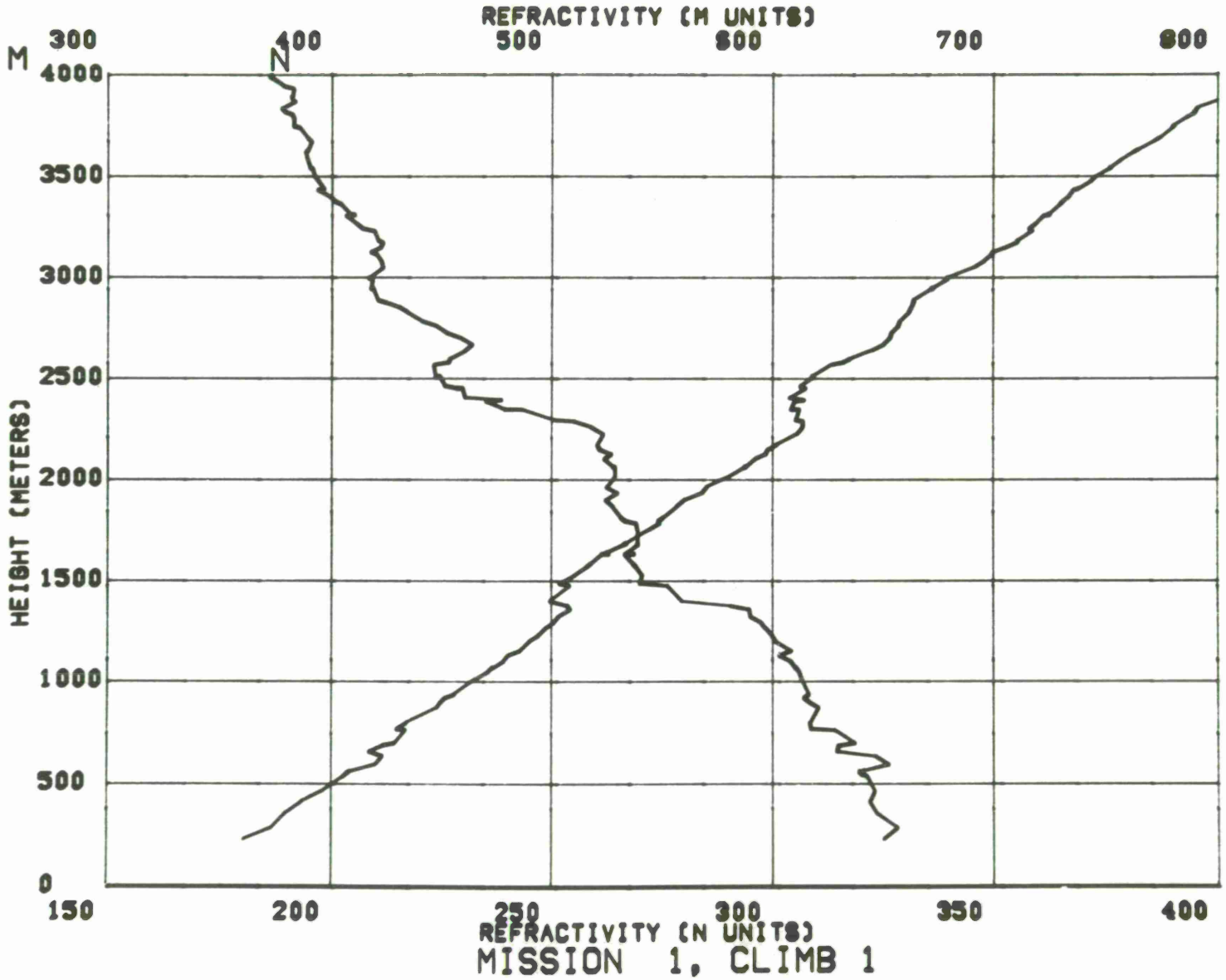
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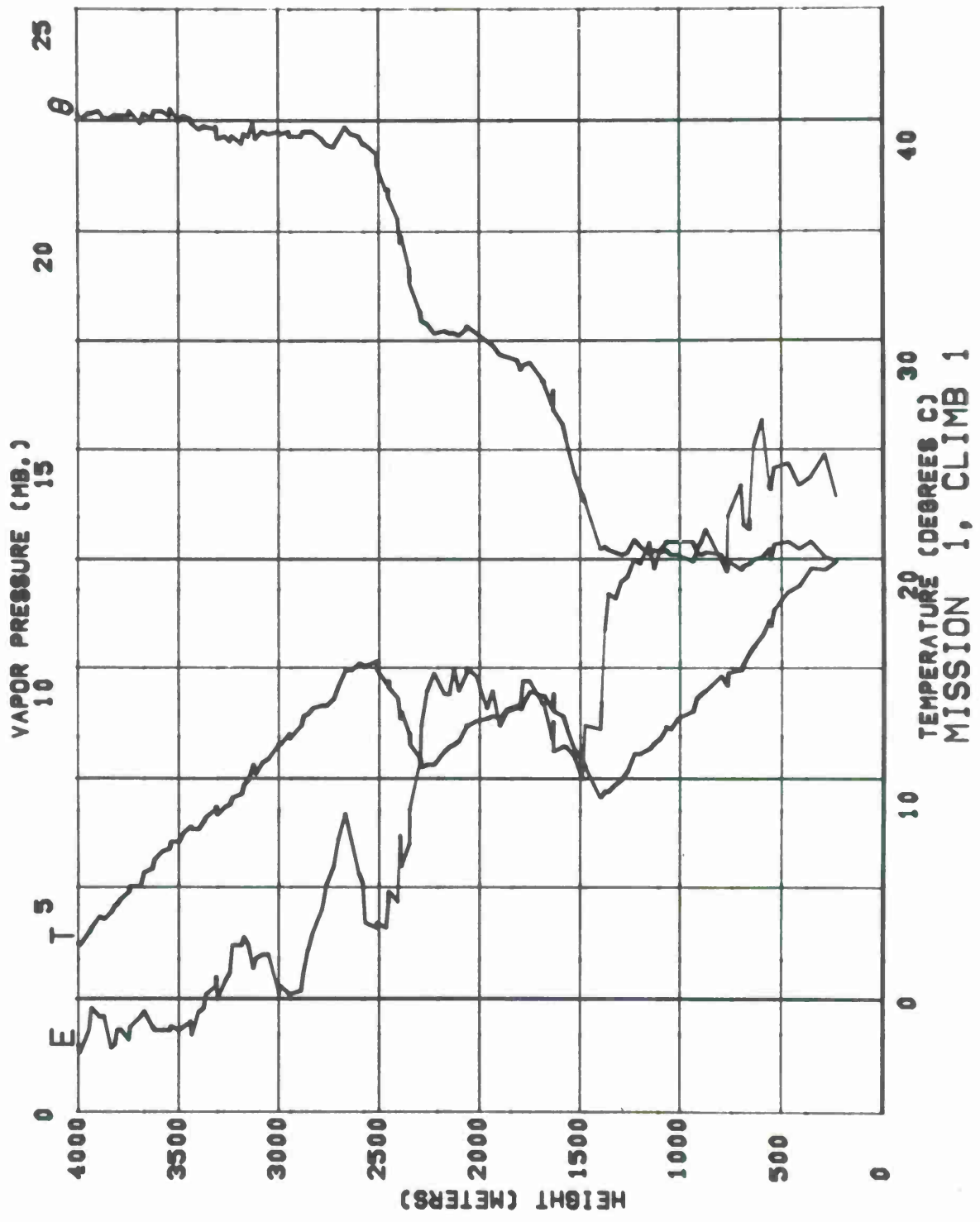
REFRACTIVITY (N UNITS)
MISSION 1, CLIMB 1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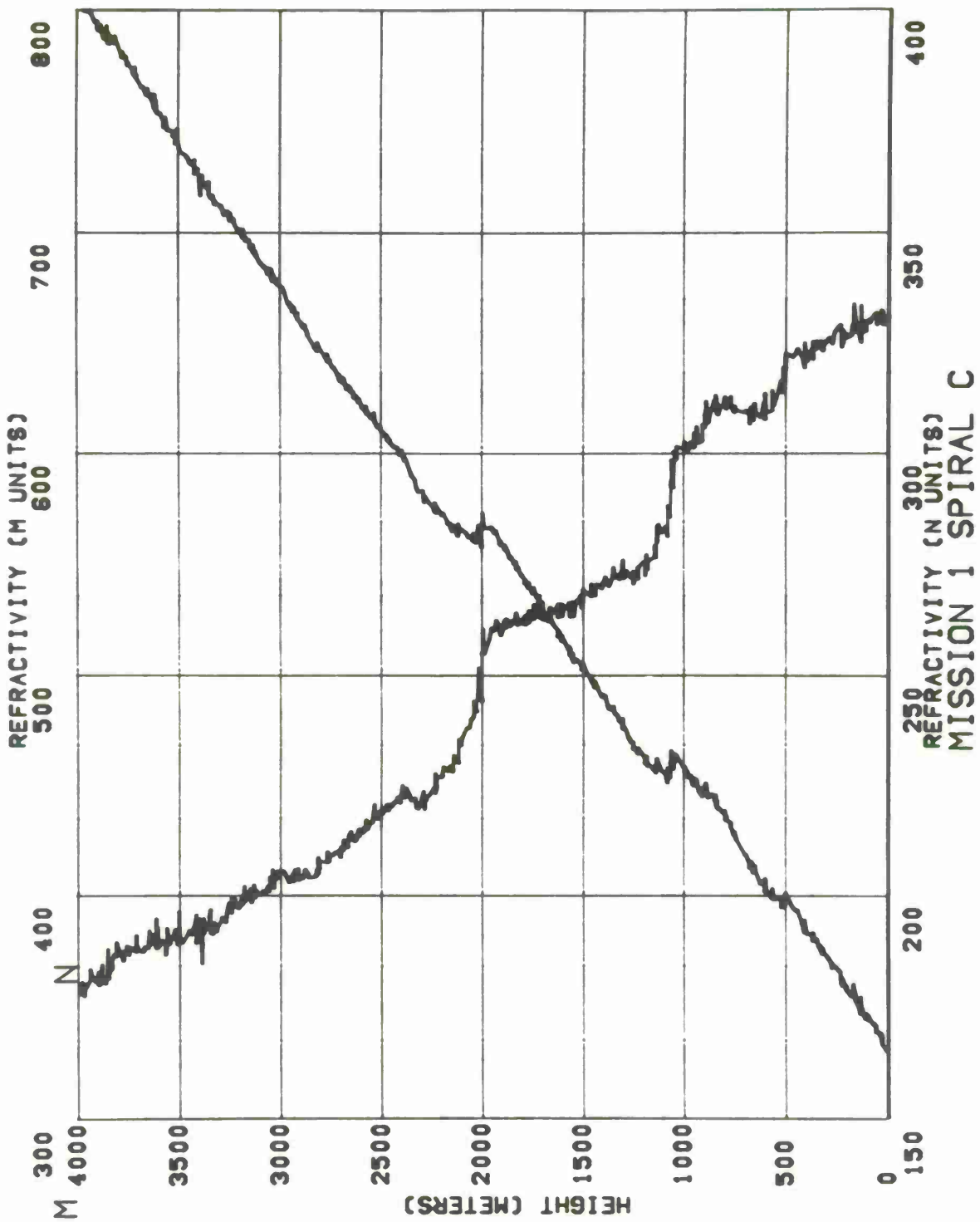
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REFRACTIVITY (N UNITS)
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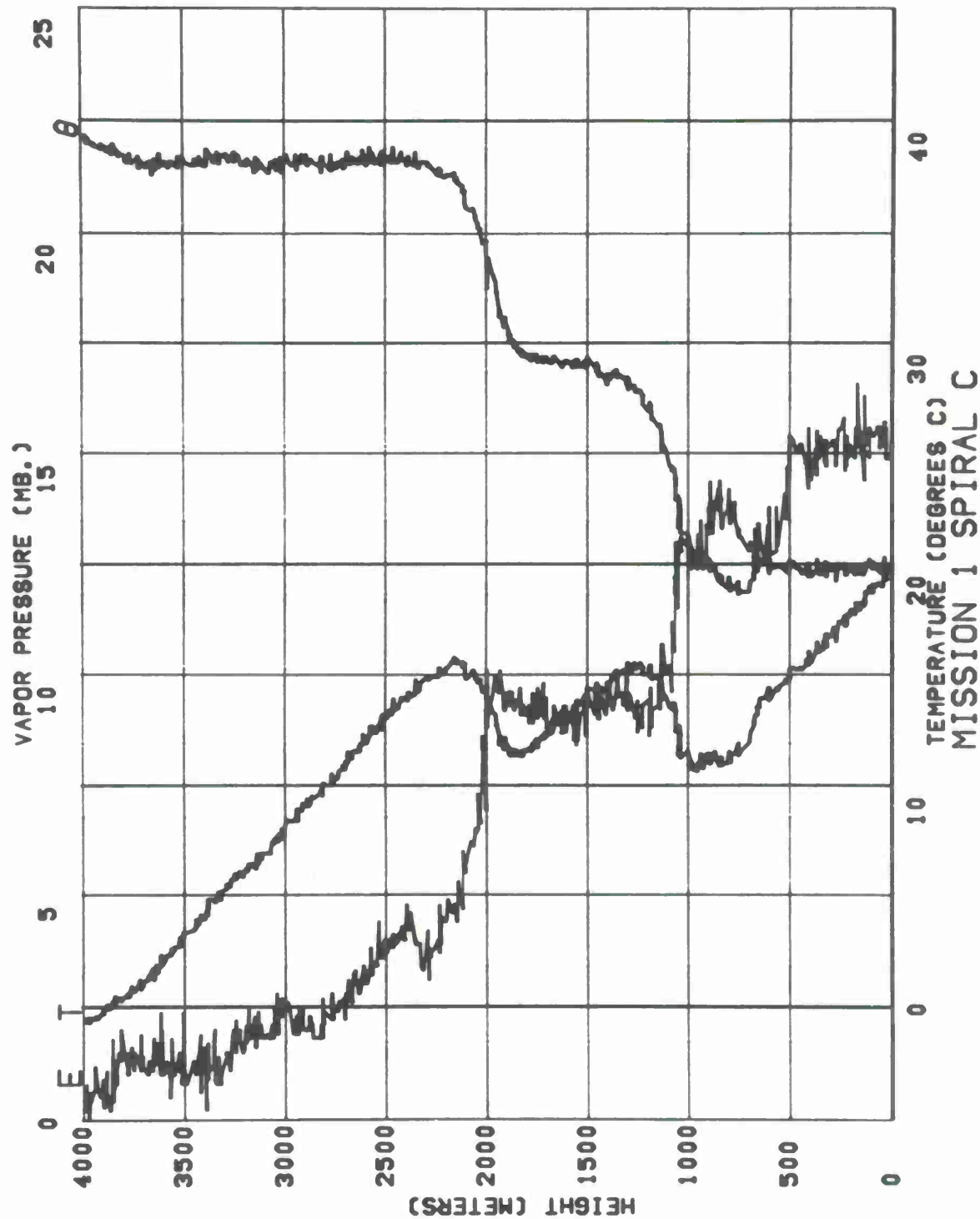
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MISSION NO. 2

Date: 6 March 1969

On the same flight path (Path I) and as a continuation of the same aircraft flight of Mission 1, spirals were repeated at the three locations of Mission 1. The flight was terminated at Key West NAS. A total of five spirals at altitudes from 0.15 to 3.0 km were flown at

Spiral	Location	Spiral Start Time Z	Local
A	c. 24-06 N, 81-08 W	2019	1519
Climb 1			
B	a. Key West NAS	2107	1607
Climb 2			
C	b. 24-06 N, 81-51 W	2156	1657
Climb 3			
D	c. 24-06 N, 81-08 W	2235	1735
E	a. Key West NAS	2313	1813

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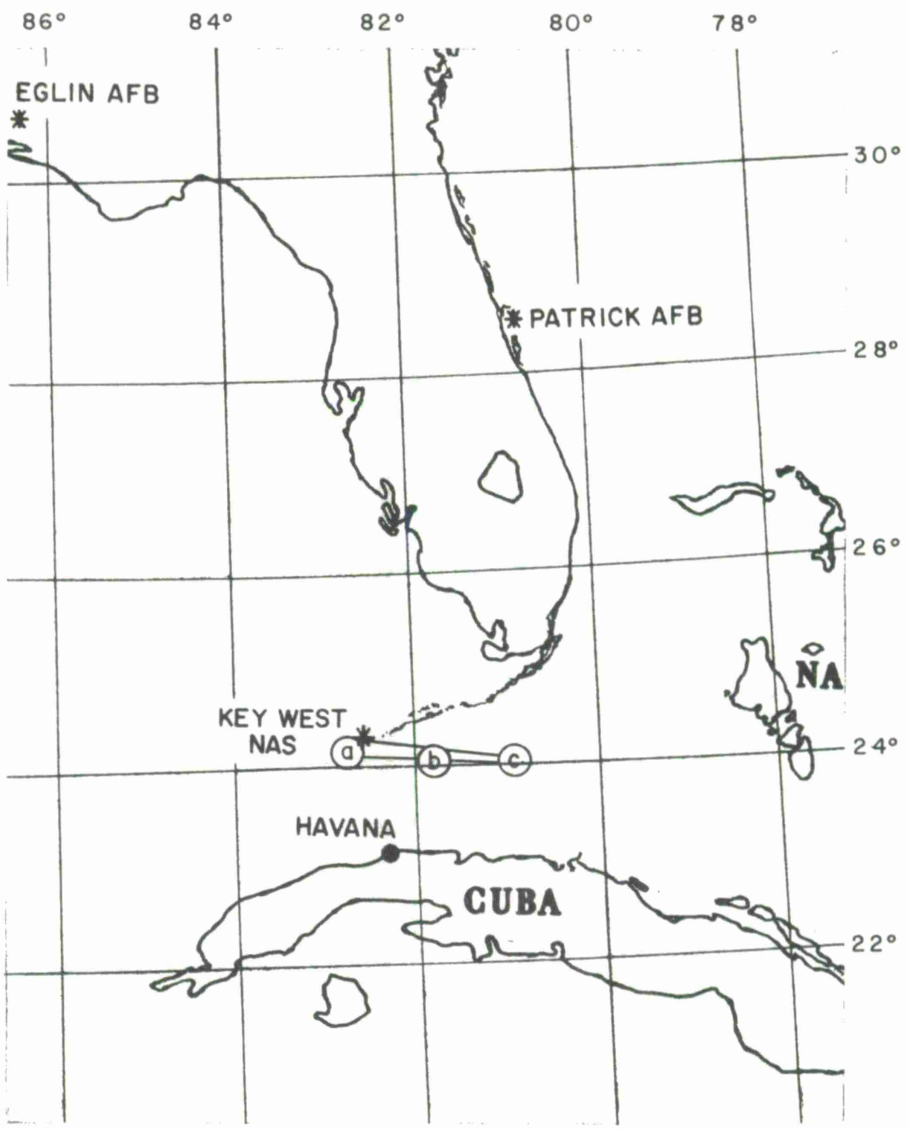

SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

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STATUTE MILES

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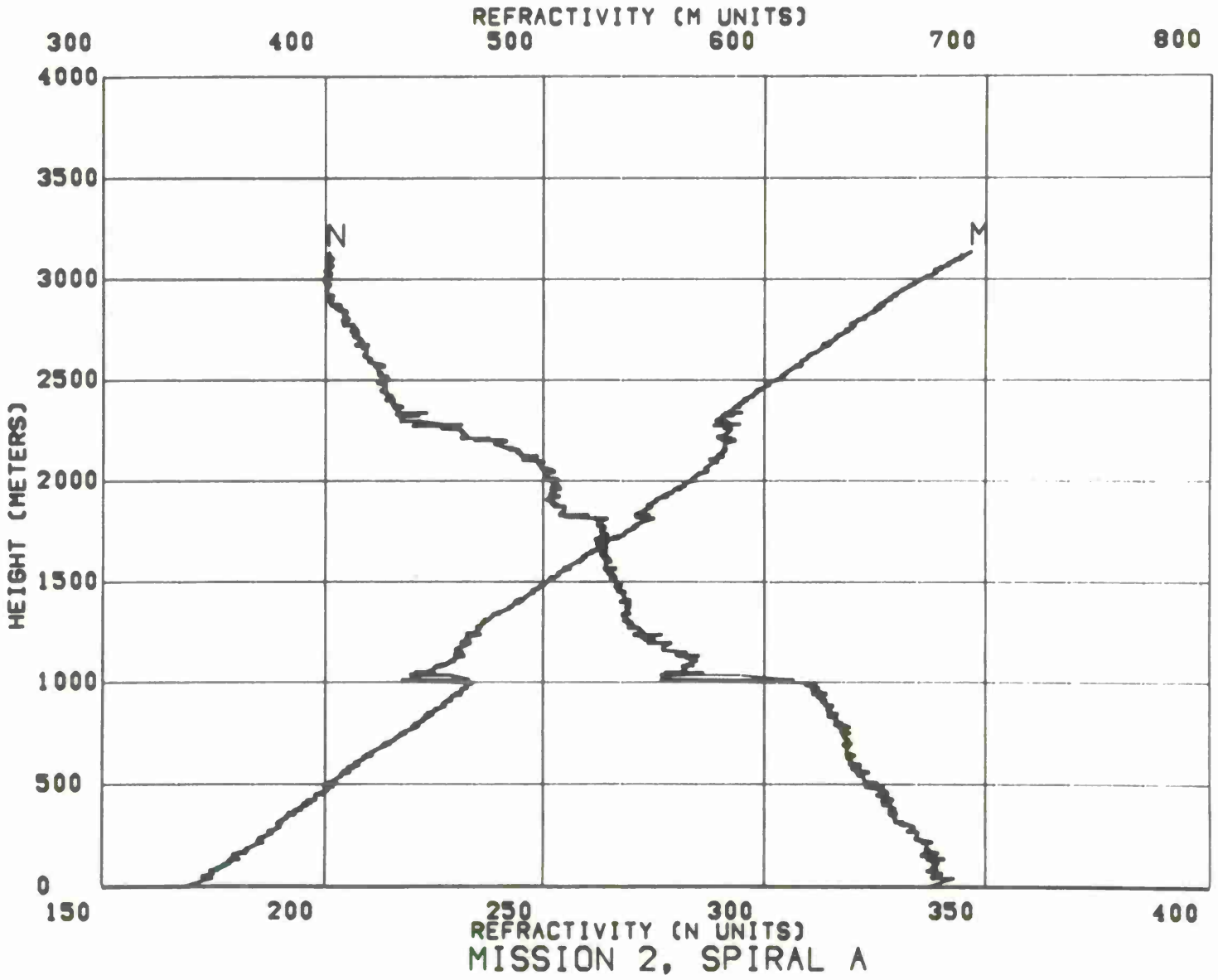
KILOMETERS

FLIGHT PATH I

MISSIONS 1 AND 2 — 6 MARCH 1969

MISSIONS 9, 10, AND 11 — 21 MARCH 1969



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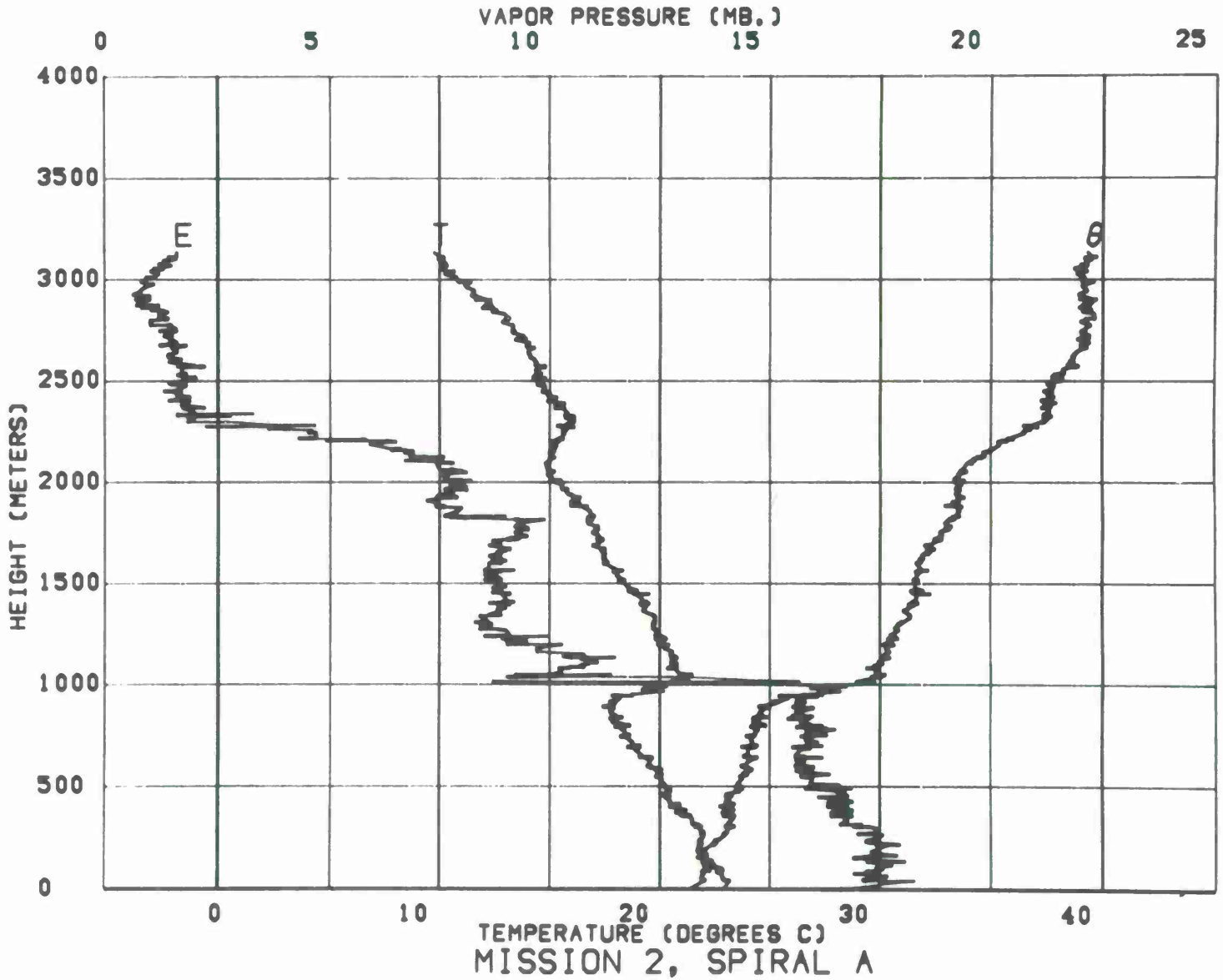

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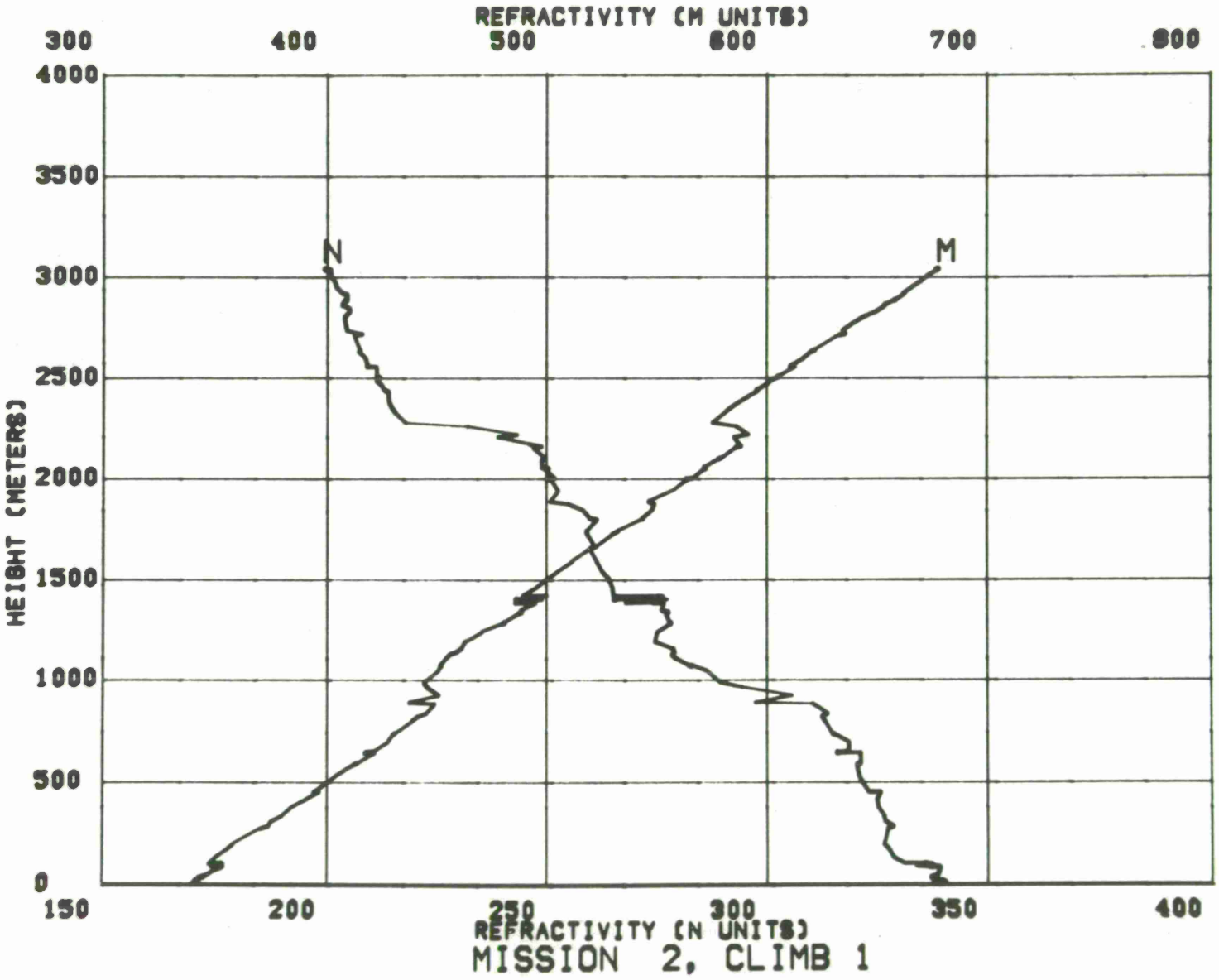

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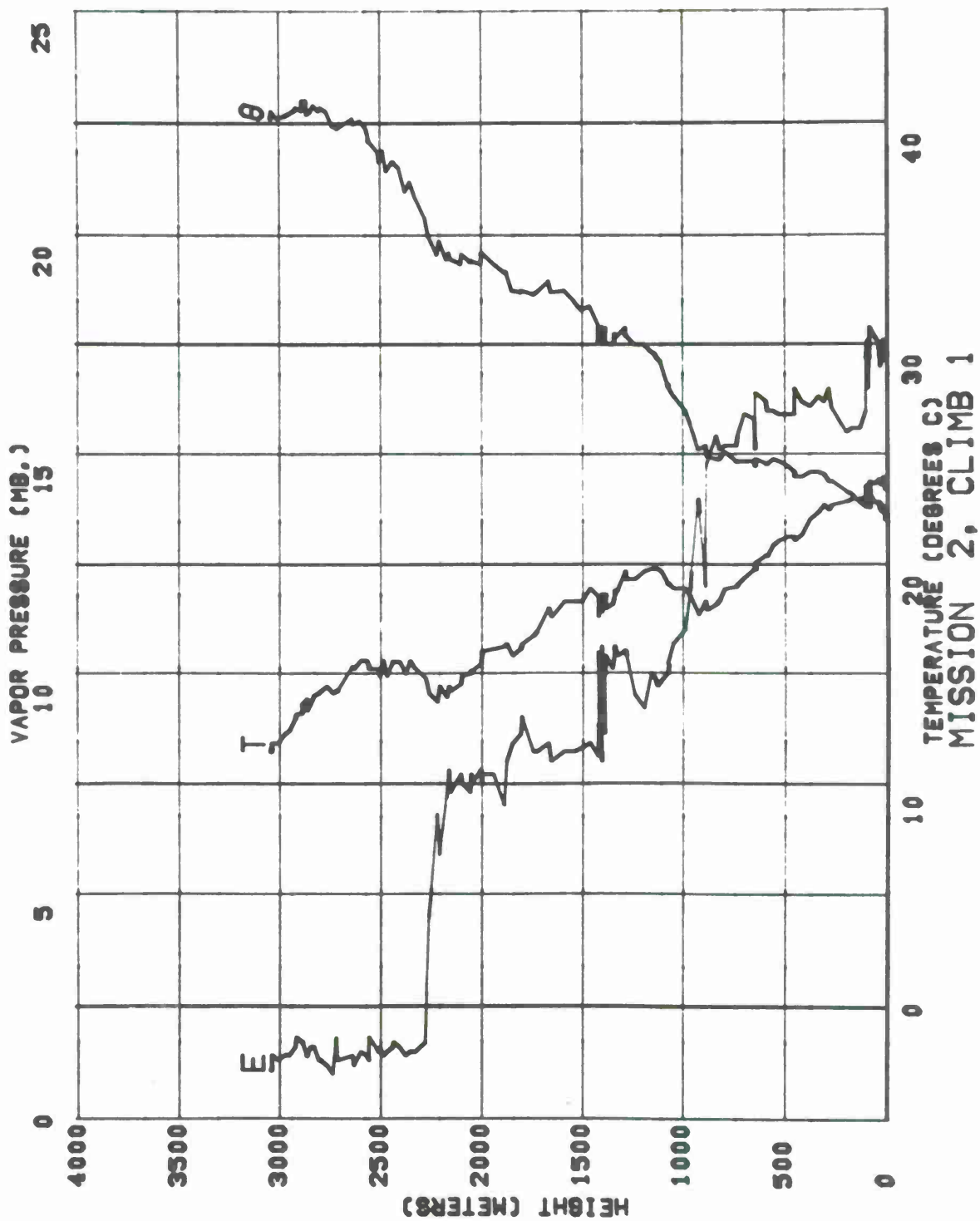
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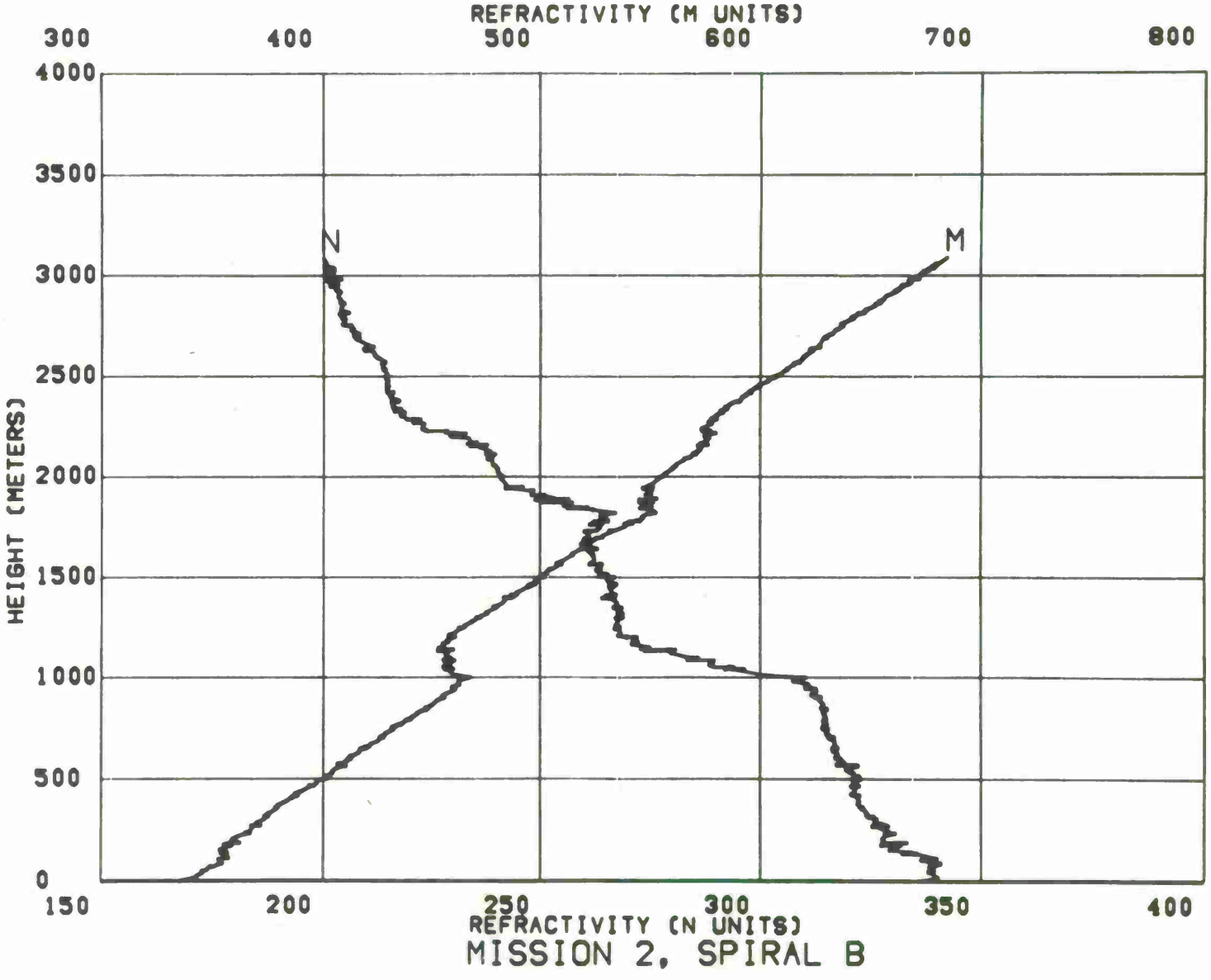

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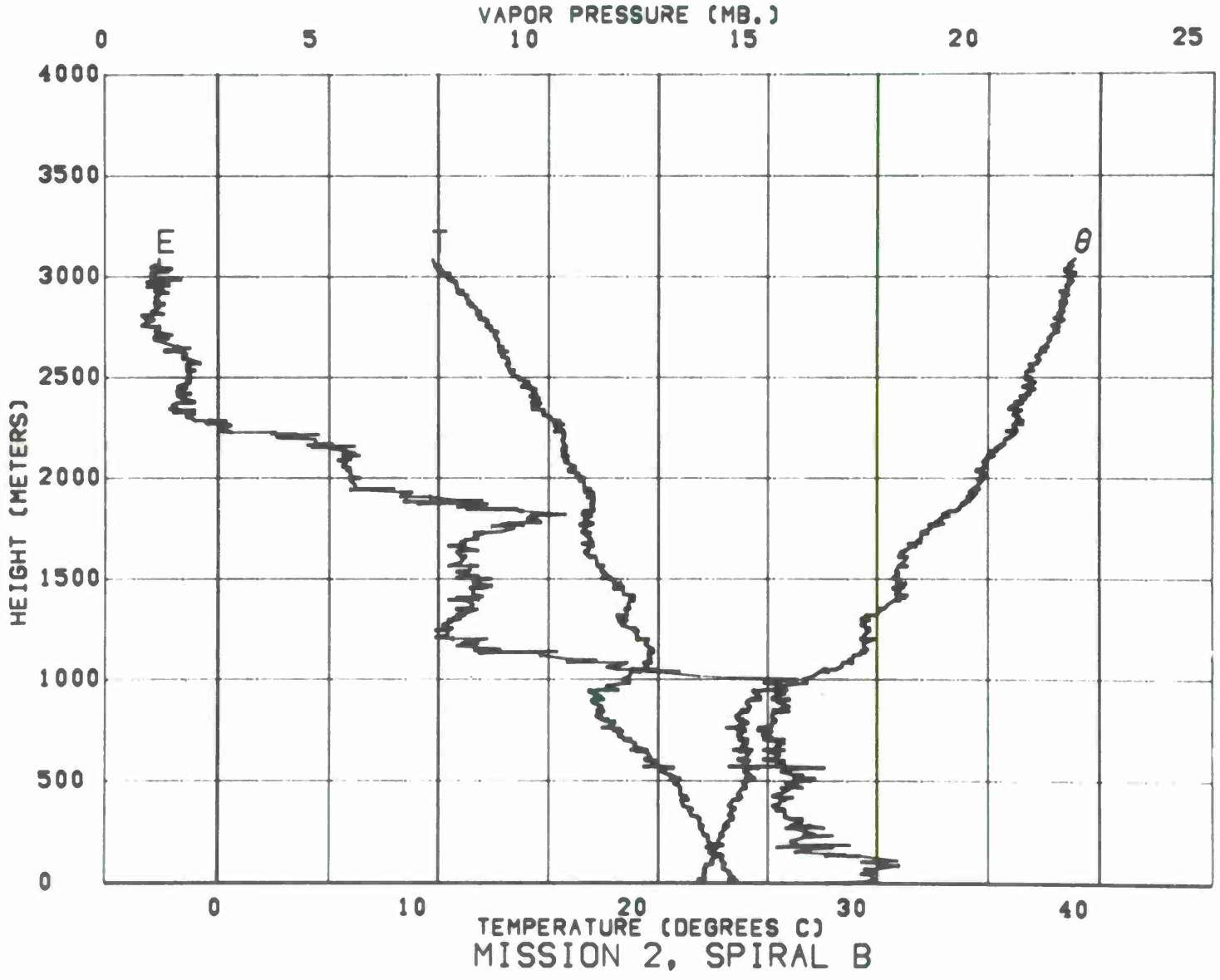

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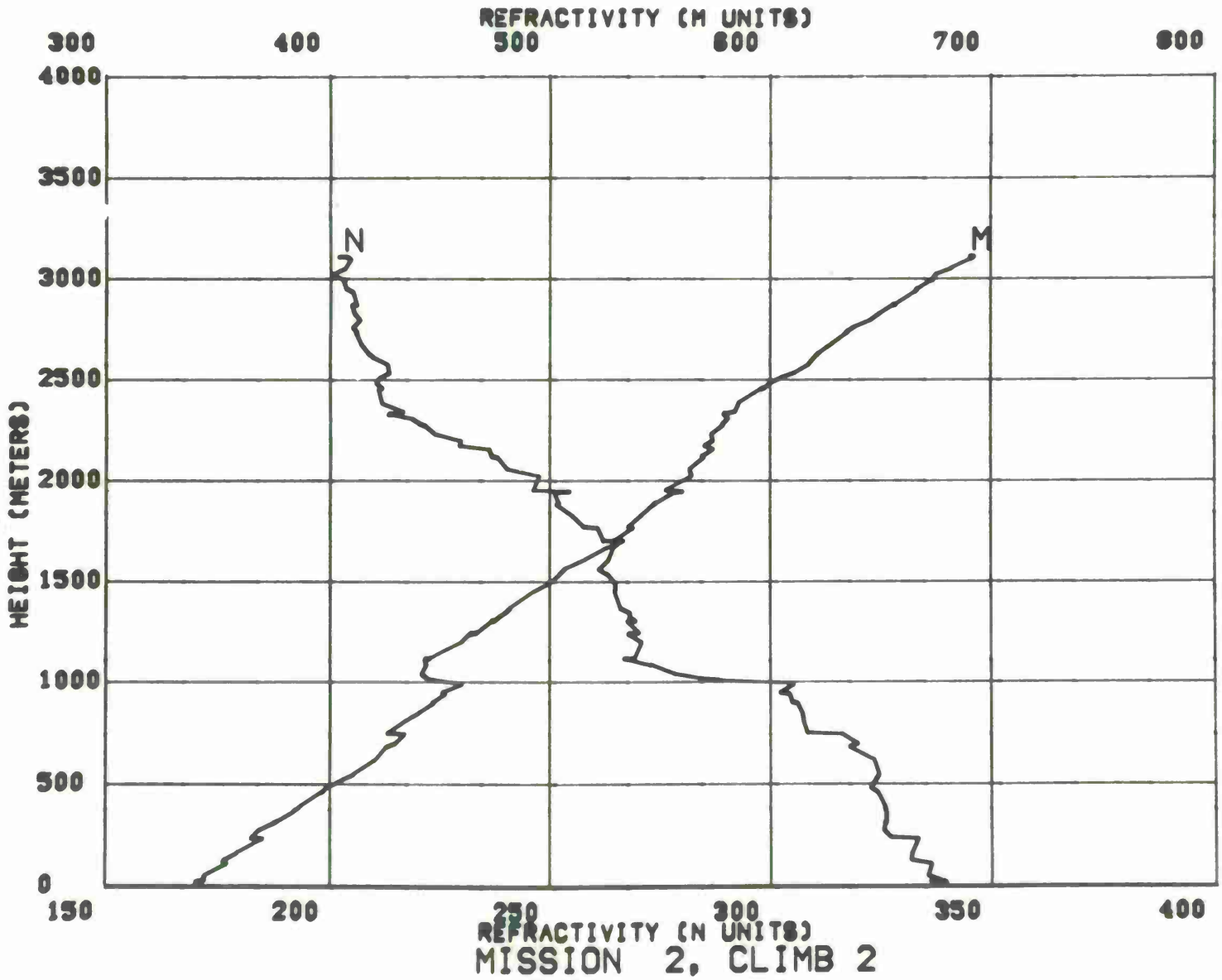

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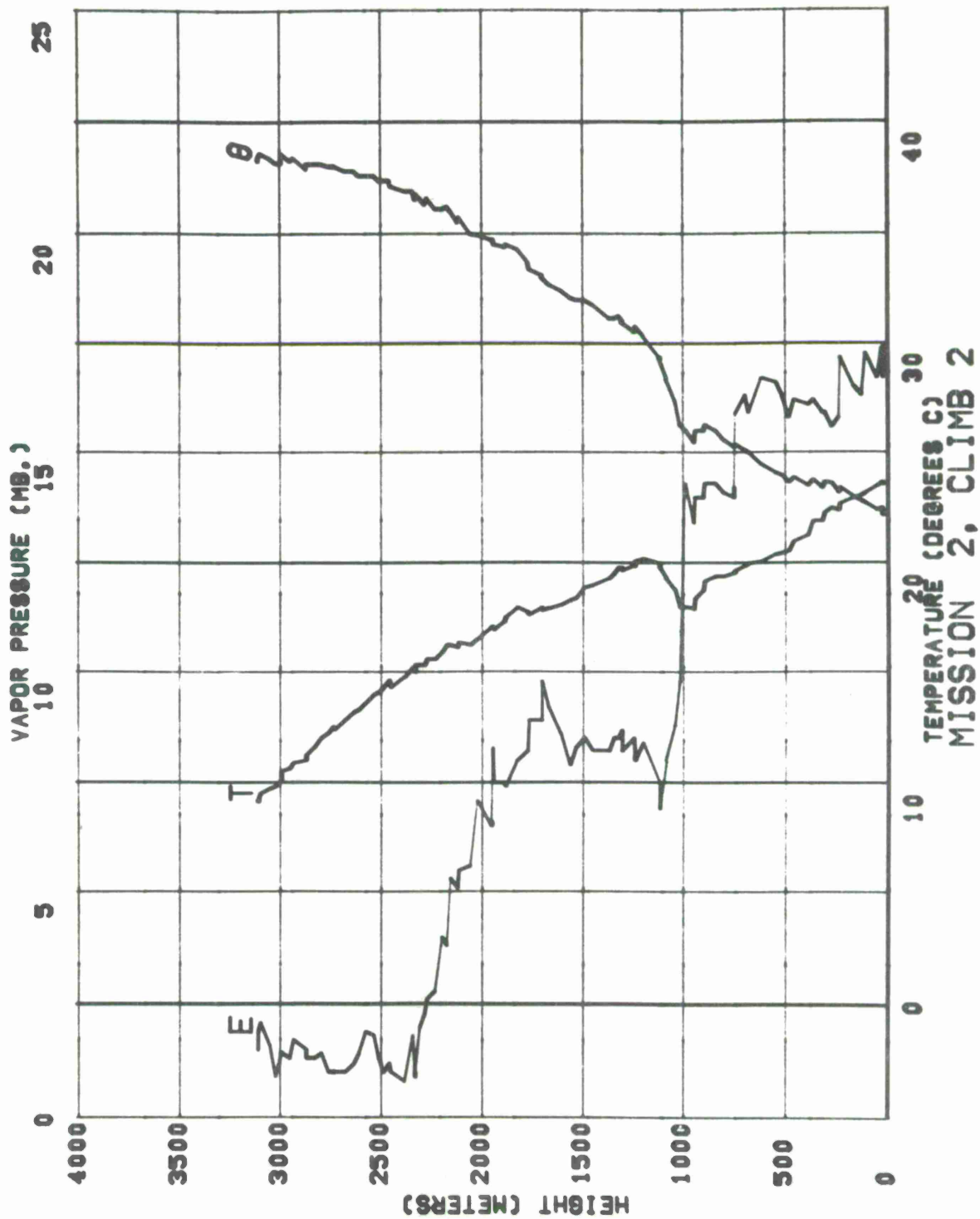
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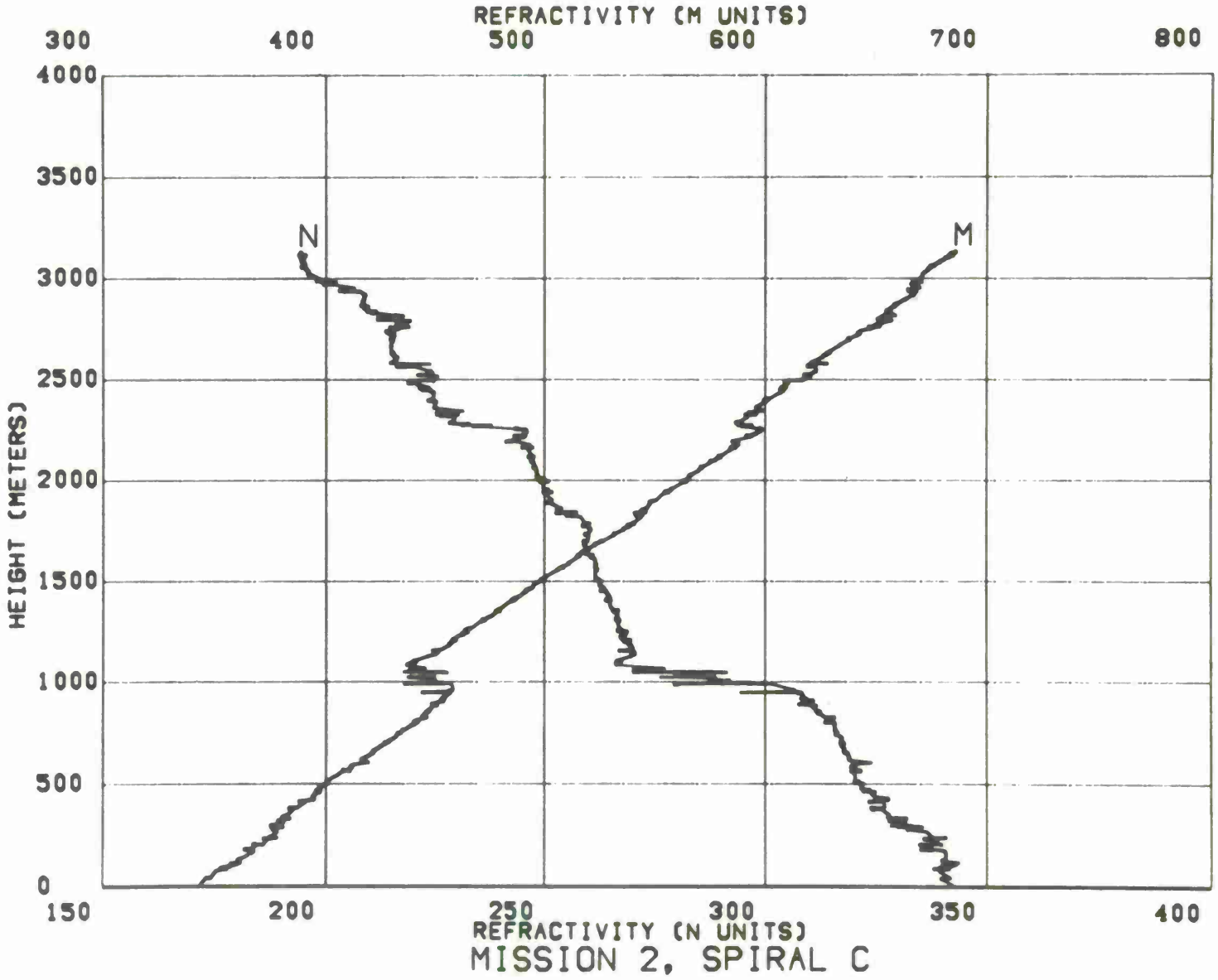
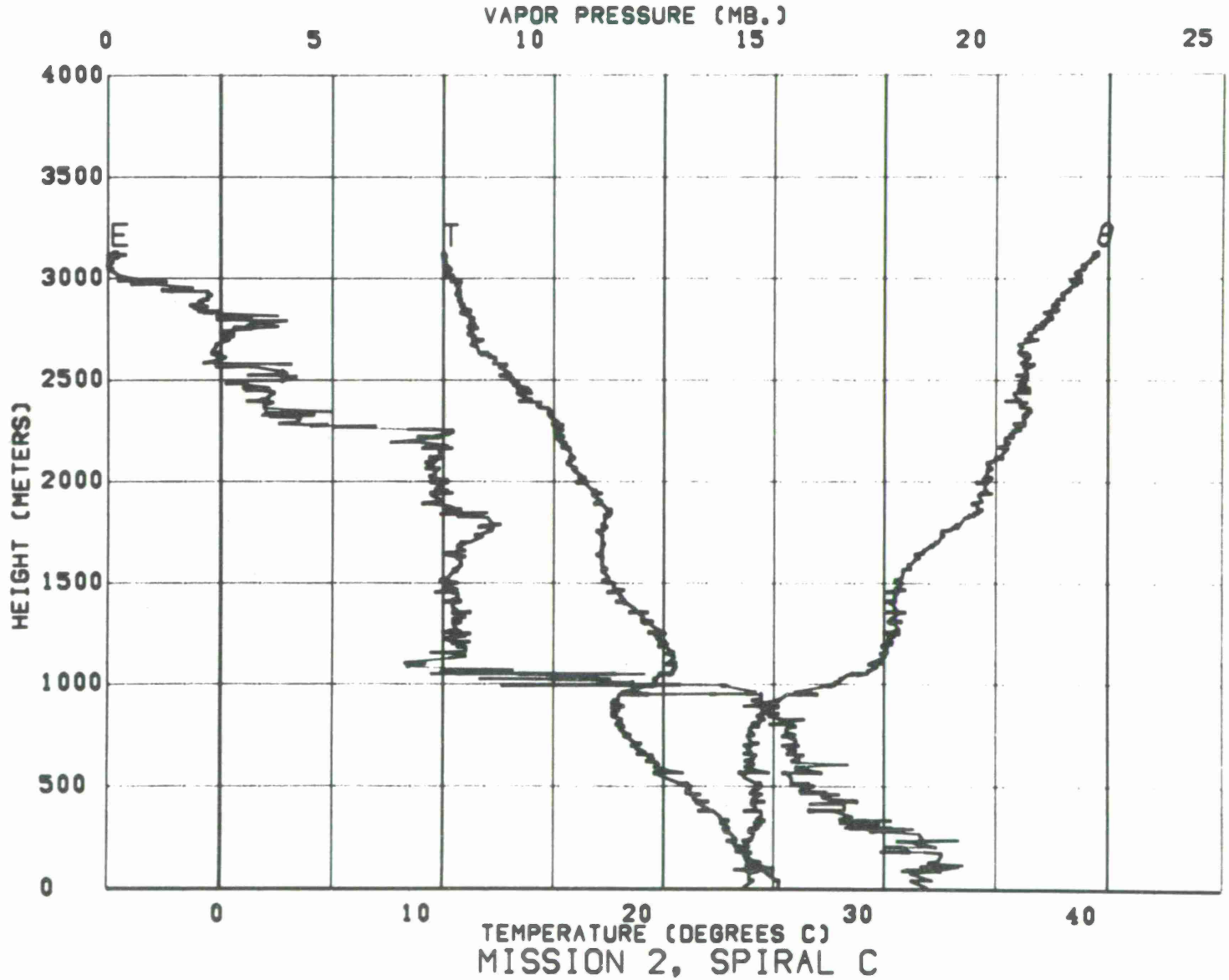
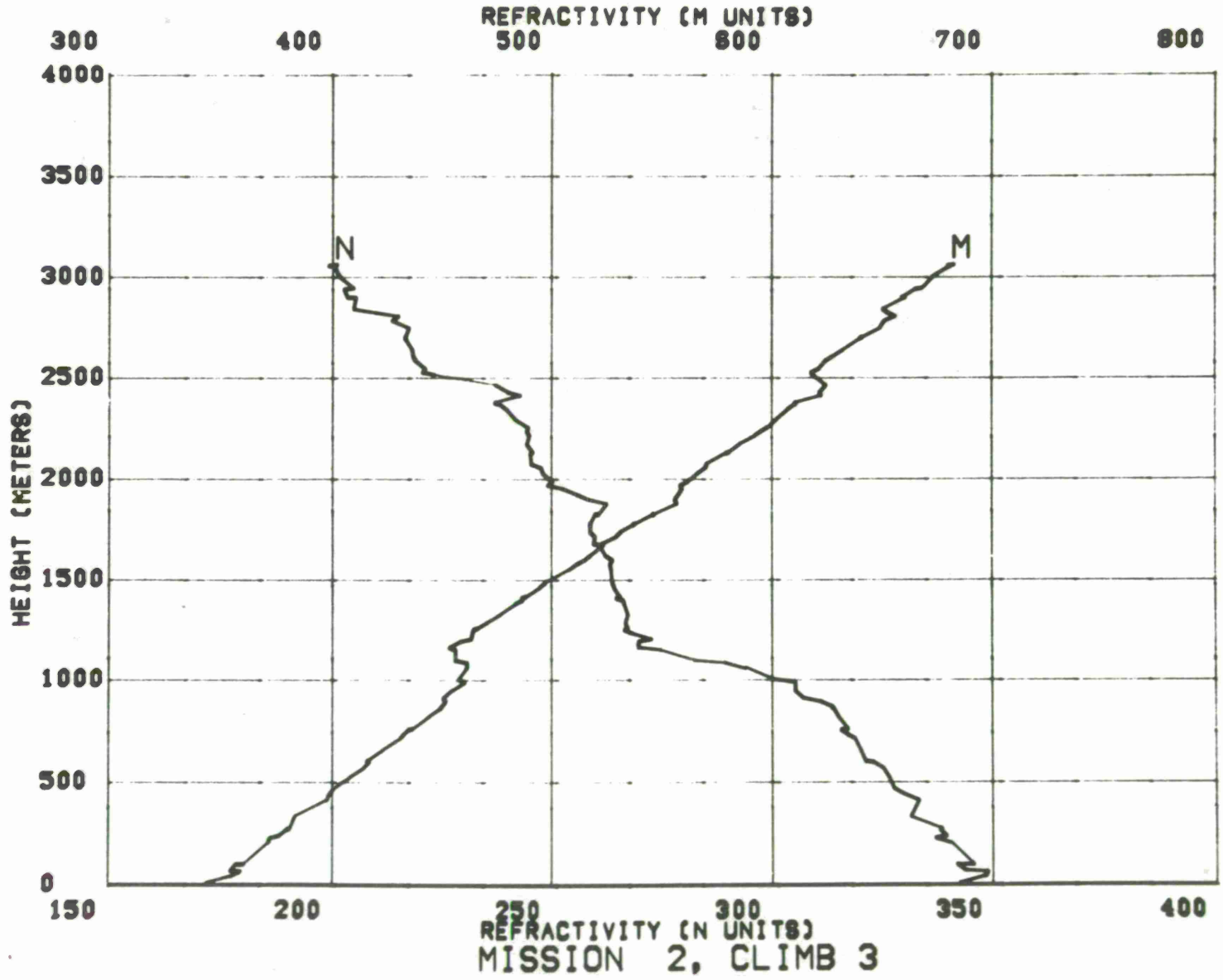
40
θ
T
E
MISSION 2, CLIMB 2



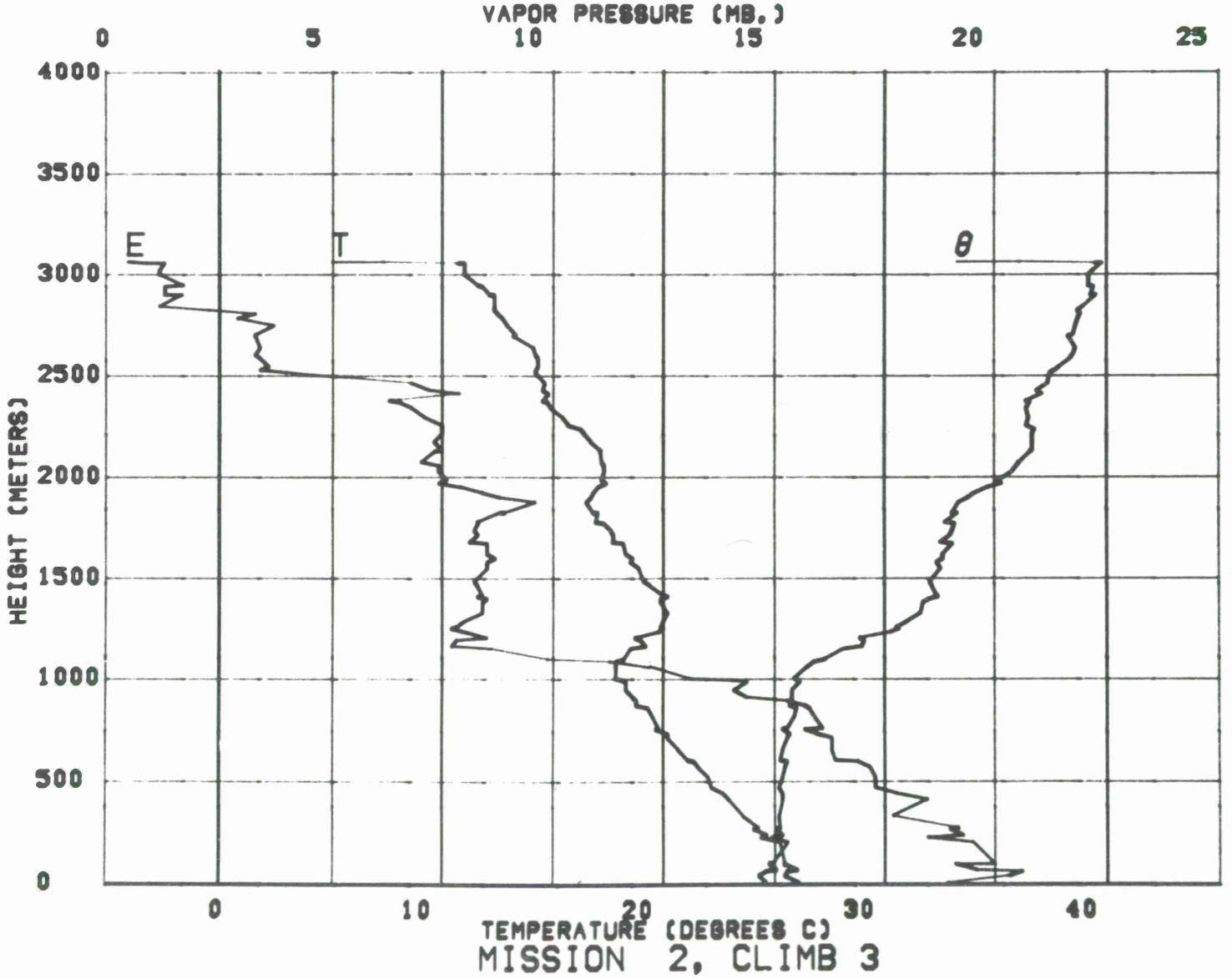
MISSION 2, SPIRAL C



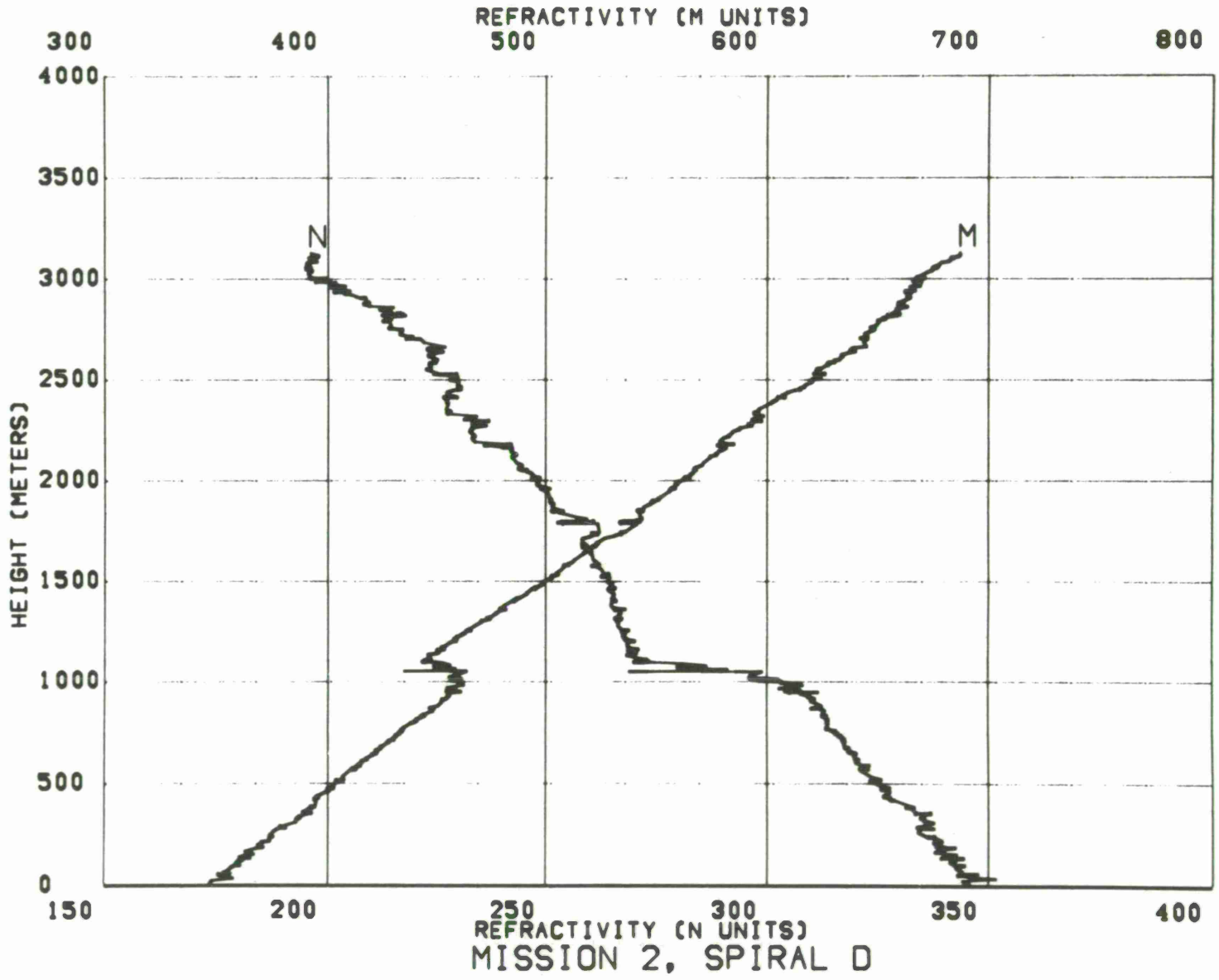
MISSION 2, SPIRAL C



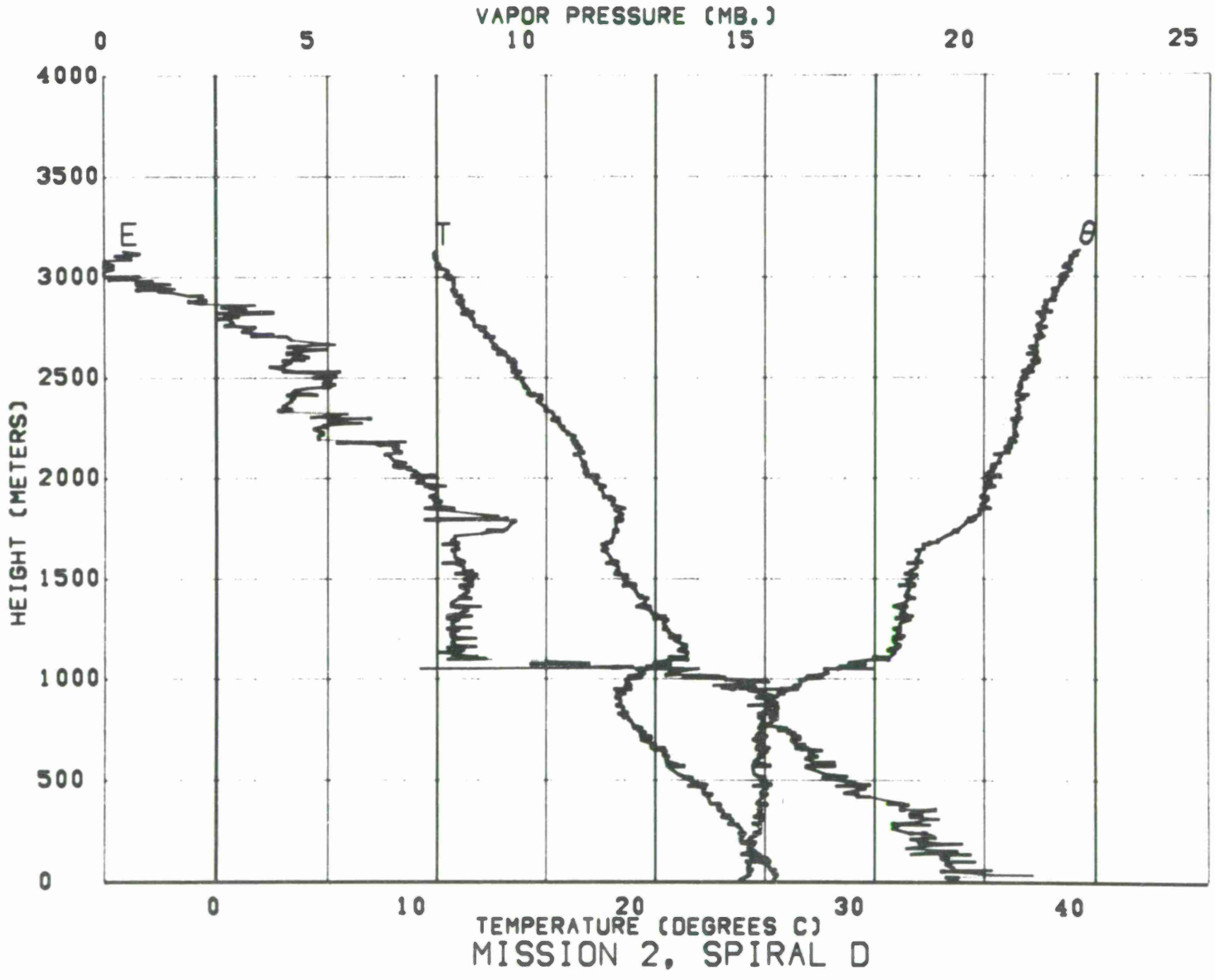
MISSION 2, CLIMB 3



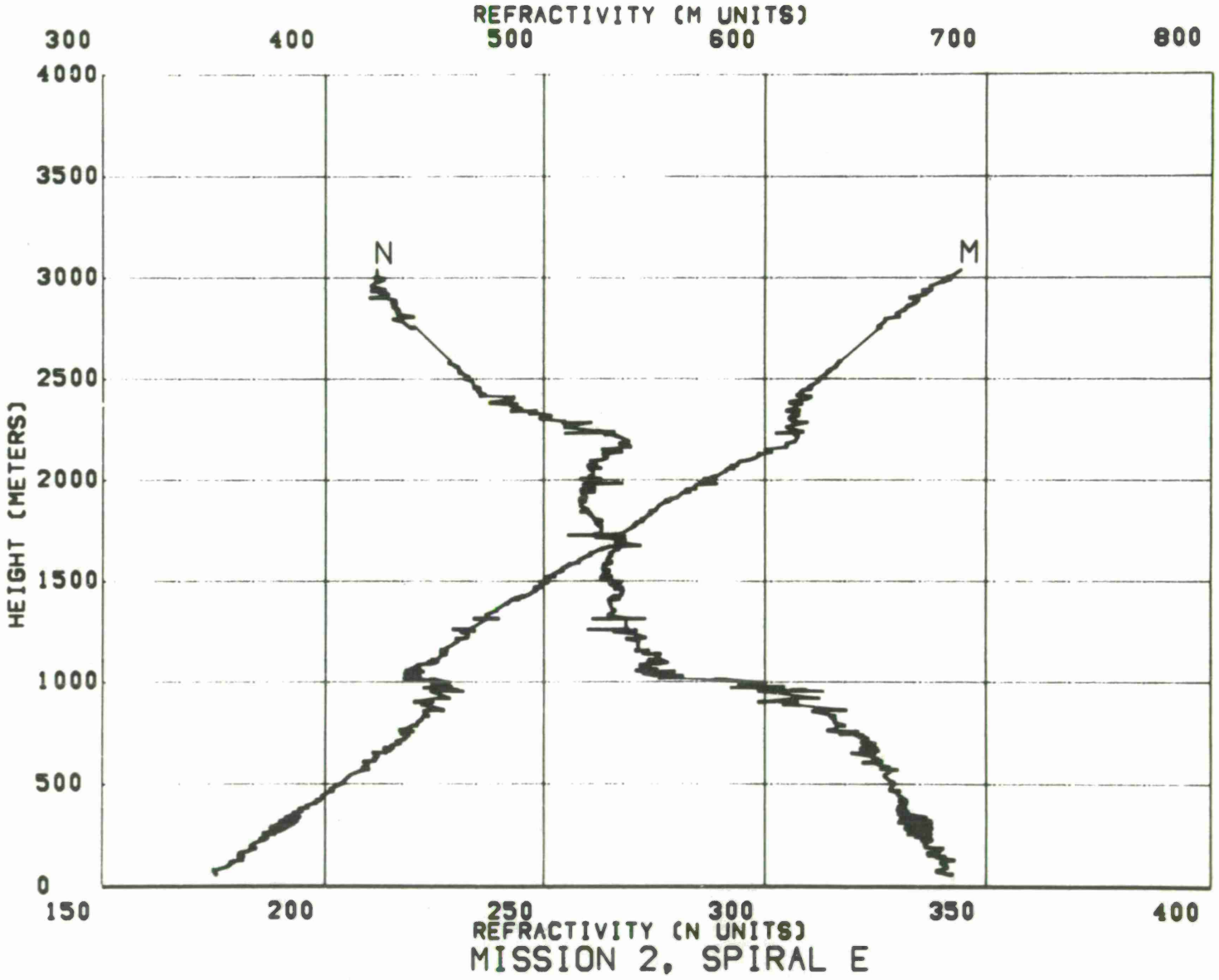
MISSION 2, CLIMB 3



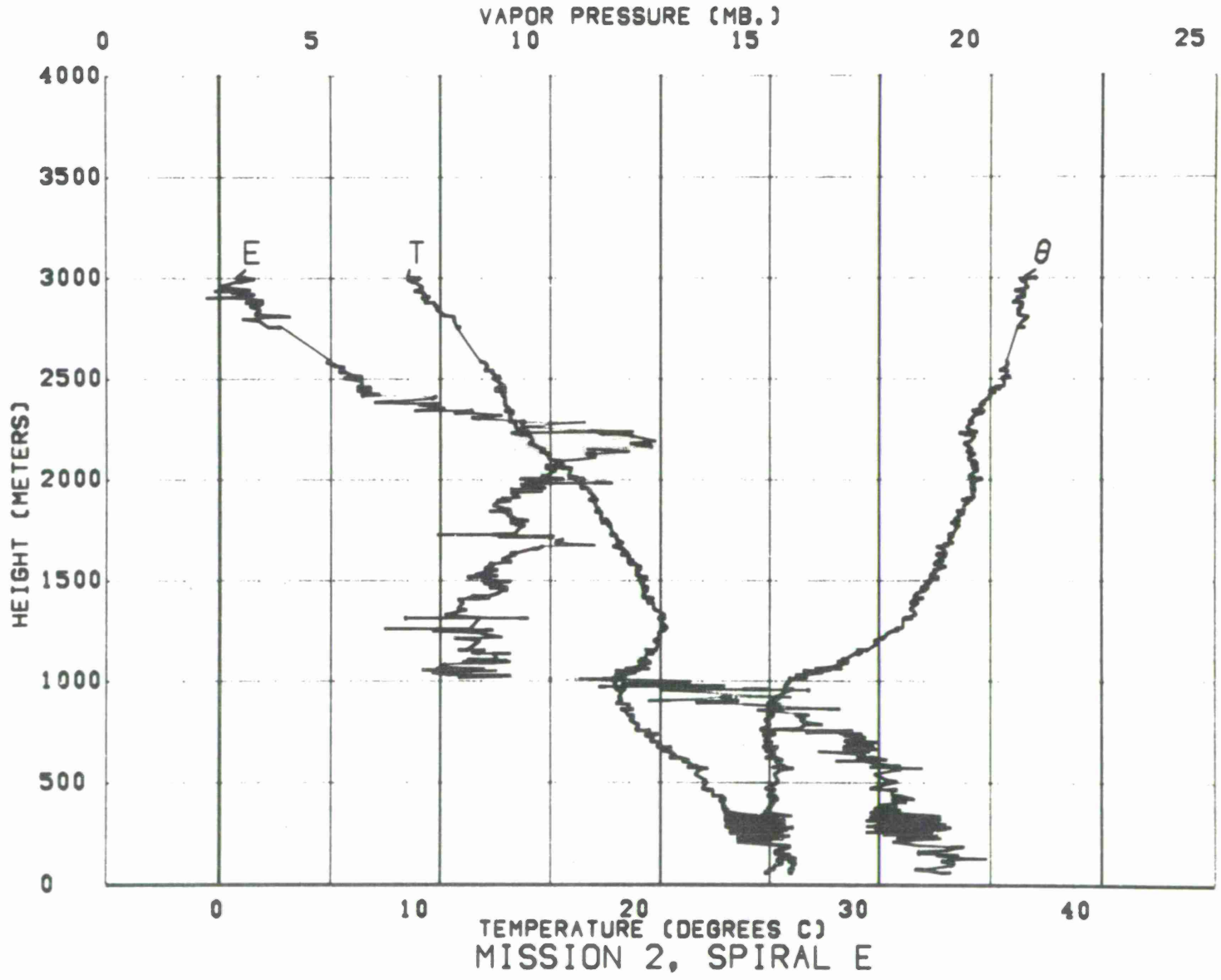
MISSION 2, SPIRAL D



MISSION 2, SPIRAL D



MISSION 2, SPIRAL E



MISSION 2, SPIRAL E

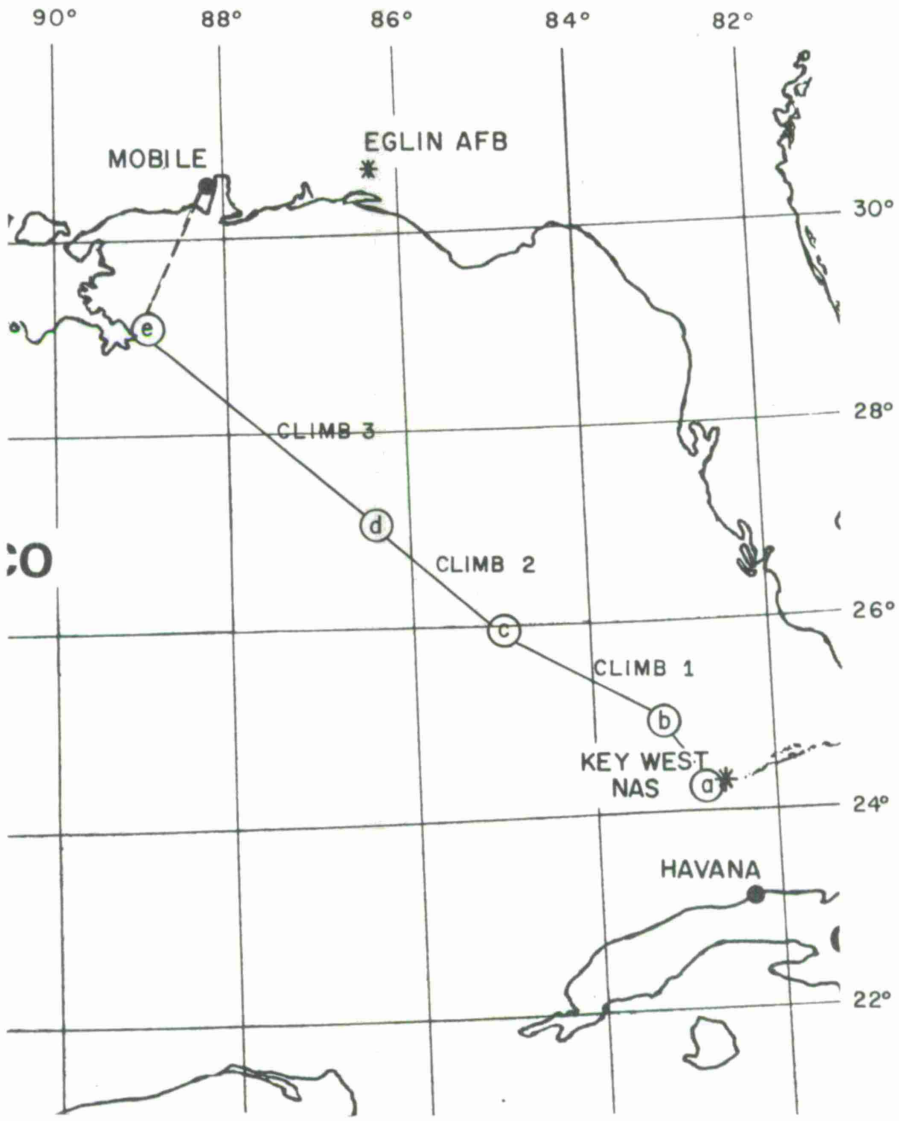
MISSION NO. 3

Date: 6 March 1969

Data were obtained on five spirals and on three ascents on a flight from Key West Naval Air Station toward New Orleans, Louisiana (Path II). The flight was terminated at Mobile, Alabama.

Spiral	Location	Spiral Start Time Z	Local
A	a. Key West NAS	1555	1055
B	b. 25-15 N, 83-15 W	1635	1135
Climb 1	b-c	1656	1156
C	c. 26-00 N, 85-00 W	1743	1243
Climb 2	c-d	1755	1255
D	d. 27-07 N, 86-20 W	1834	1334
Climb 3	d-e	1856	1356
E	e. 29-10 N, 89-07 W	2016	1516

86840



SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300

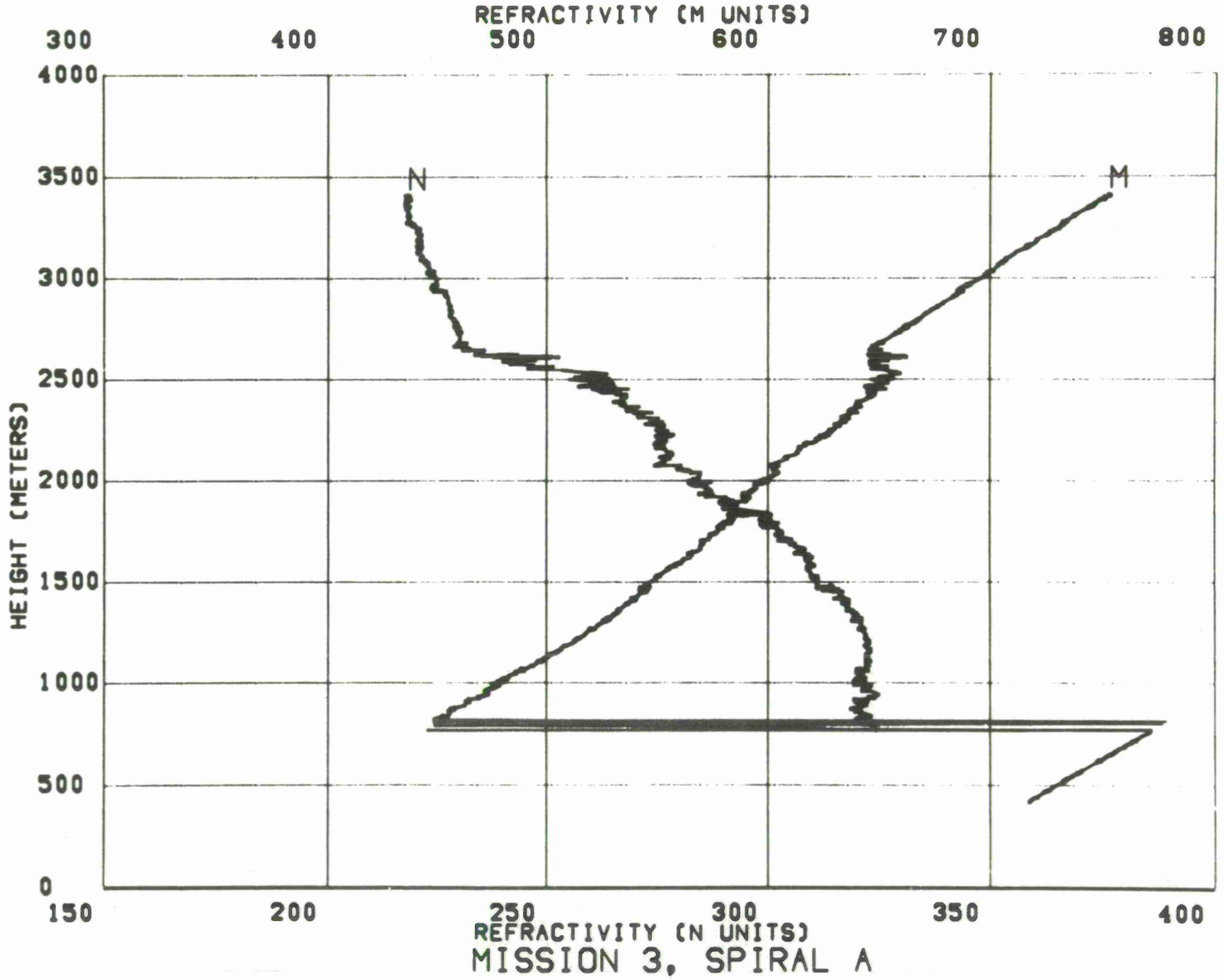
STATUTE MILES

100 50 0 100 200 300 400

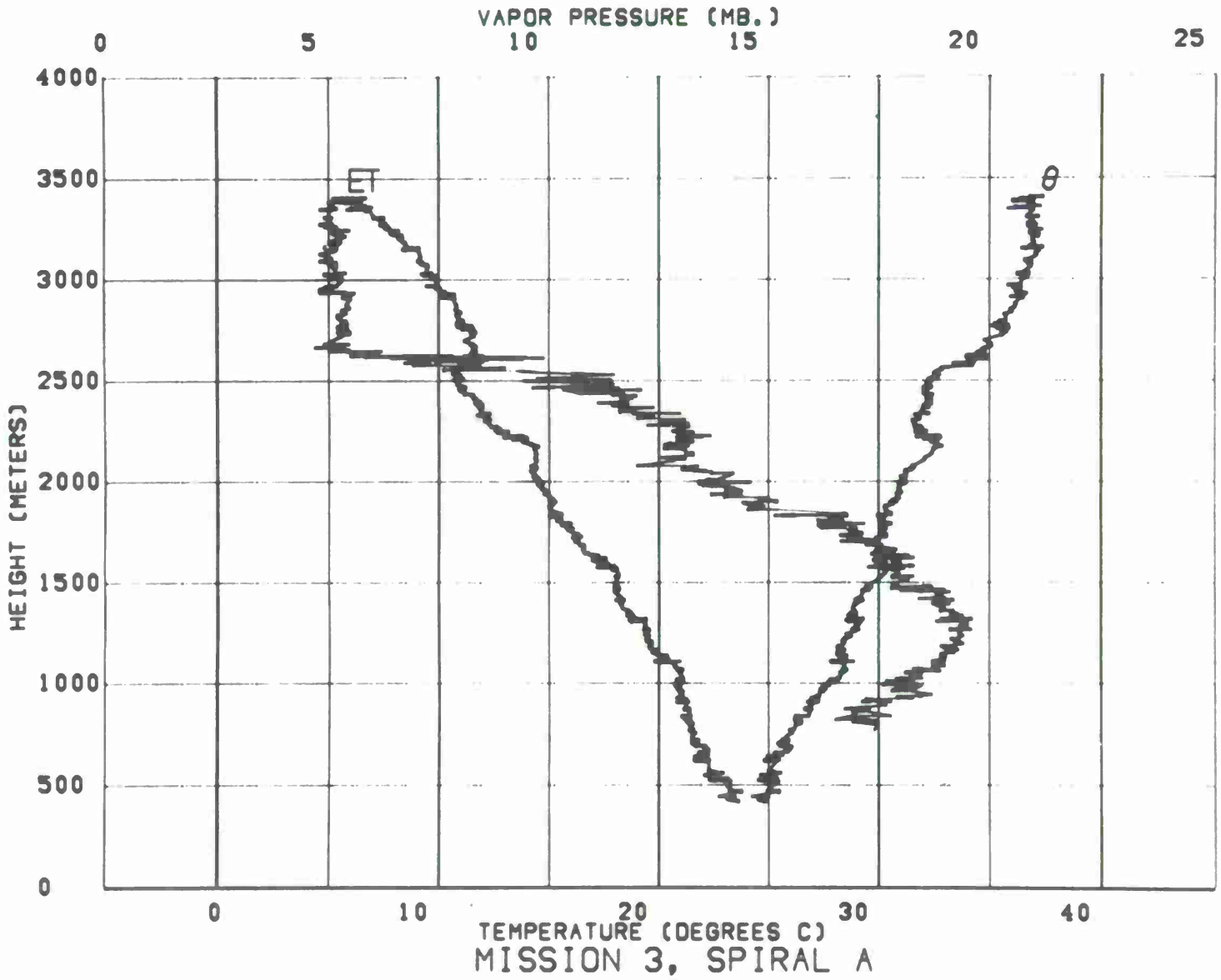
KILOMETERS

FLIGHT PATH II

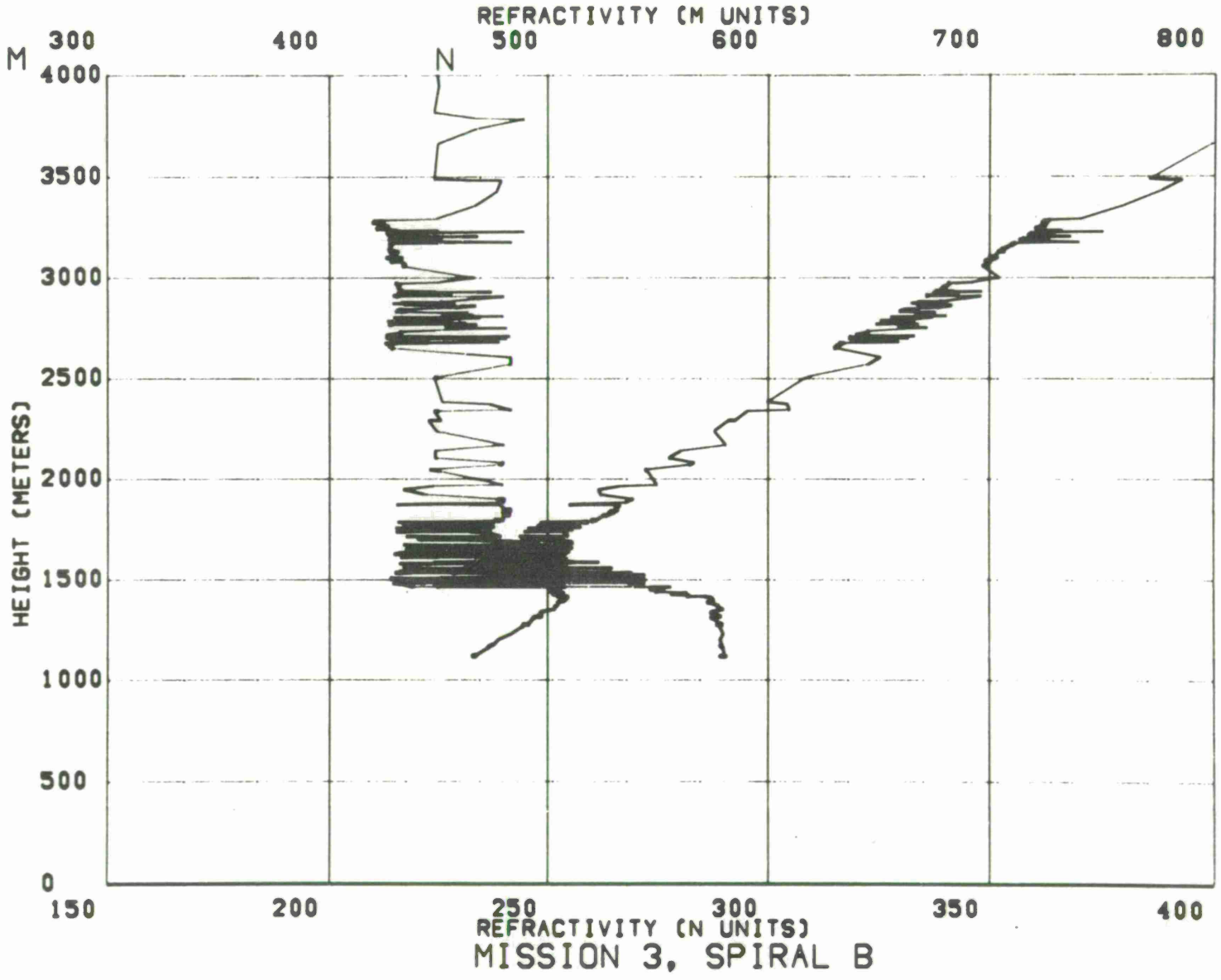
MISSION 3 — 9 MARCH 1969



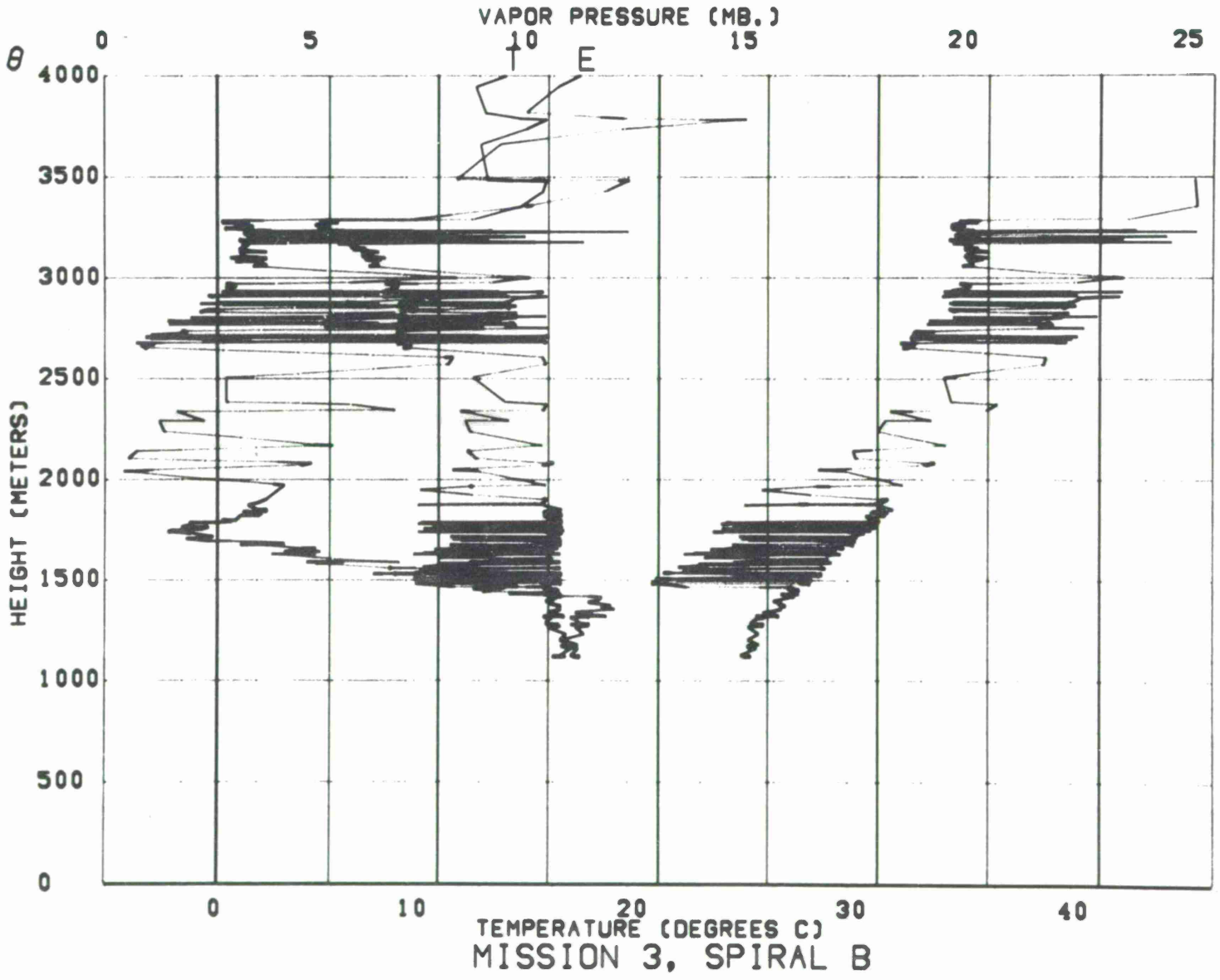
MISSION 3, SPIRAL A



MISSION 3, SPIRAL A



MISSION 3, SPIRAL B


VAPOR PRESSURE (MB.)
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25
θ
E
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3500
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2500
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HEIGHT (METERS)
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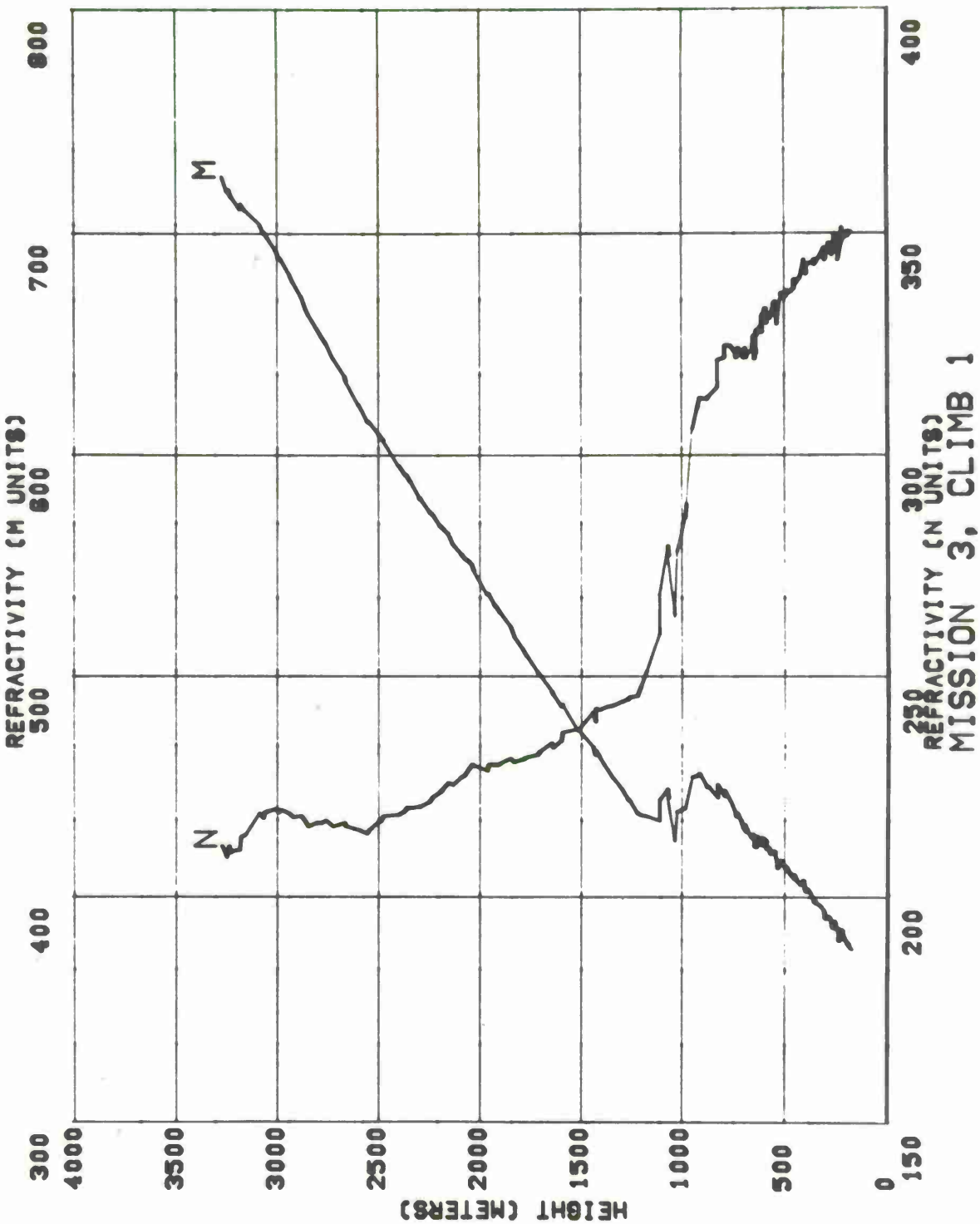
TEMPERATURE (DEGREES C)
MISSION 3, SPIRAL B


REFRACTIVITY (M UNITS)
300
400
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700
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HEIGHT (METERS)
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3500
3000
2500
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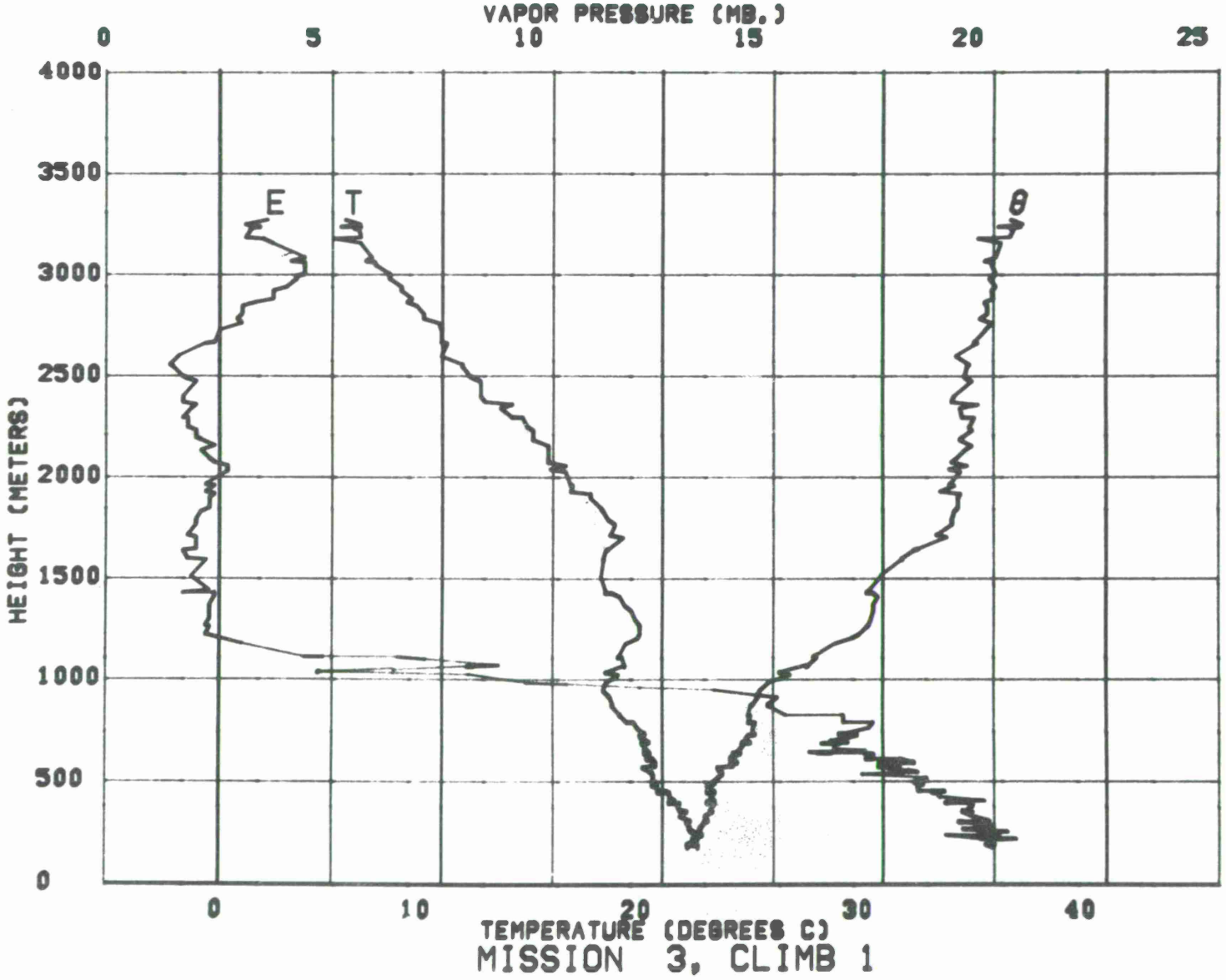
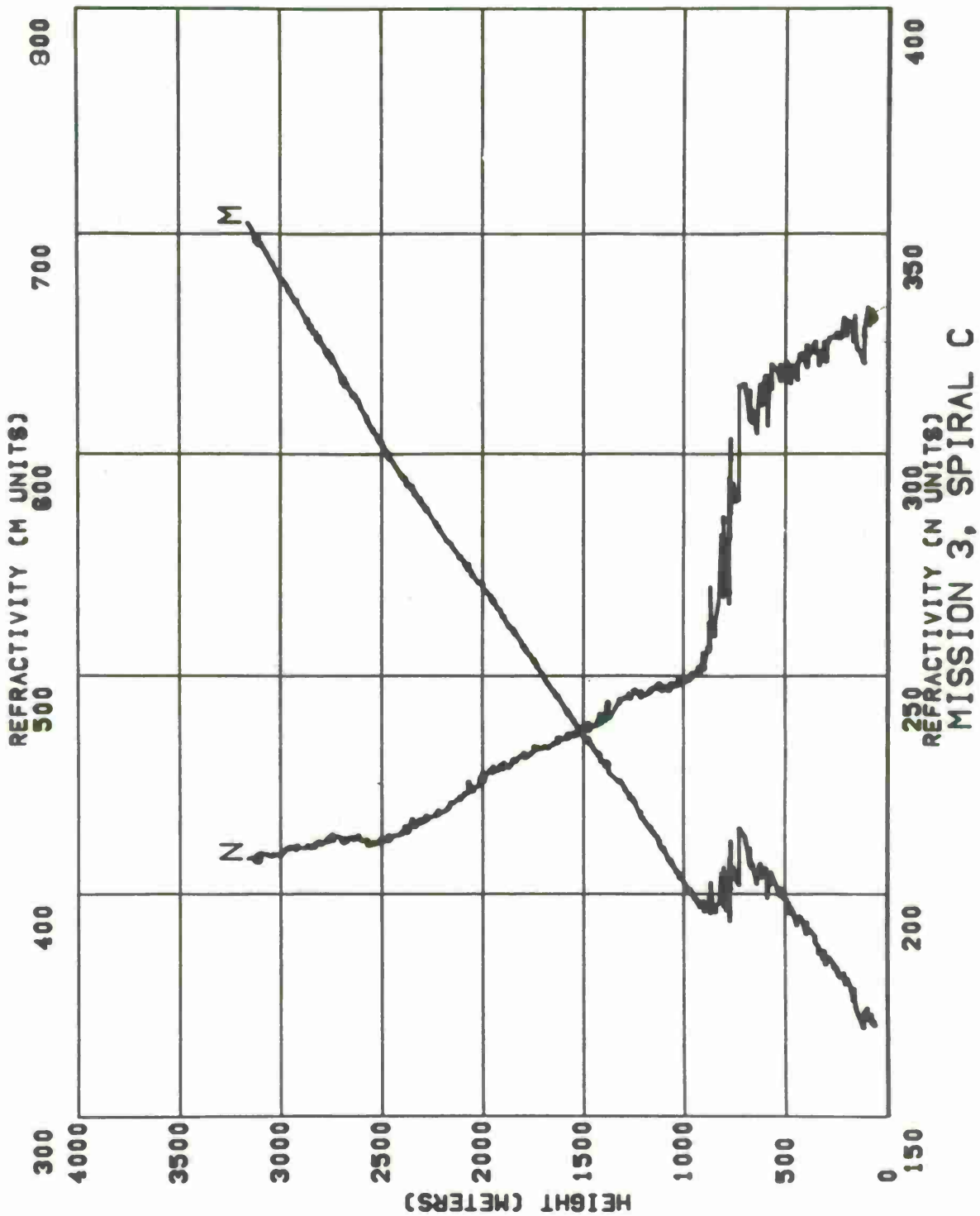
500
0
M
N
REFRACTIVITY (N UNITS)
150
200
250
300
350
400
MISSION 3, CLIMB 1



MISSION 3, CLIMB 1


MISSION 3, SPIRAL C
M
N
REFRACTIVITY (M UNITS)
300
400
500
600
700
800
REFRACTIVITY (N UNITS)
150
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250
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HEIGHT (METERS)
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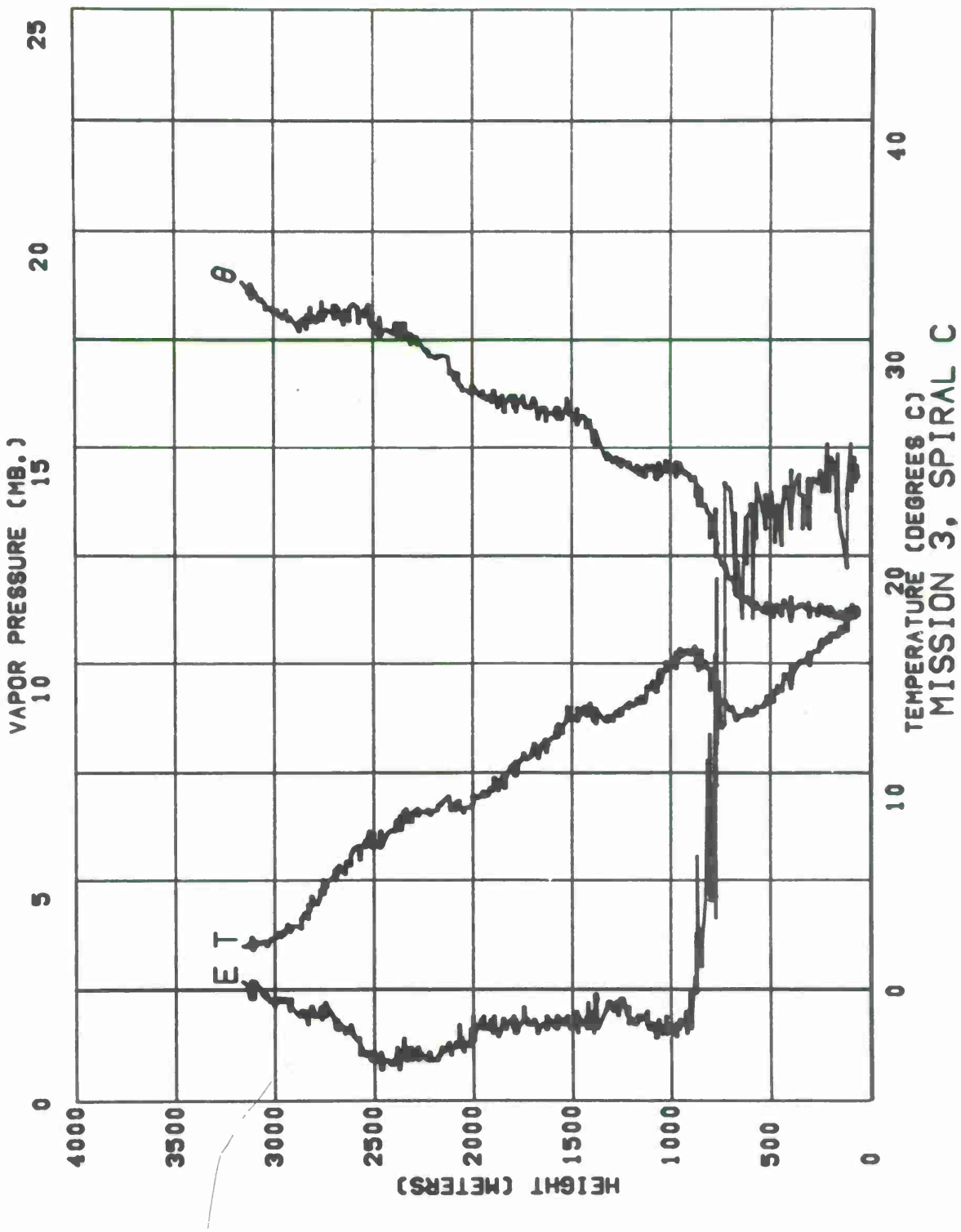
4000


VAPOR PRESSURE (MB.)
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HEIGHT (METERS)
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TEMPERATURE (DEGREES C)
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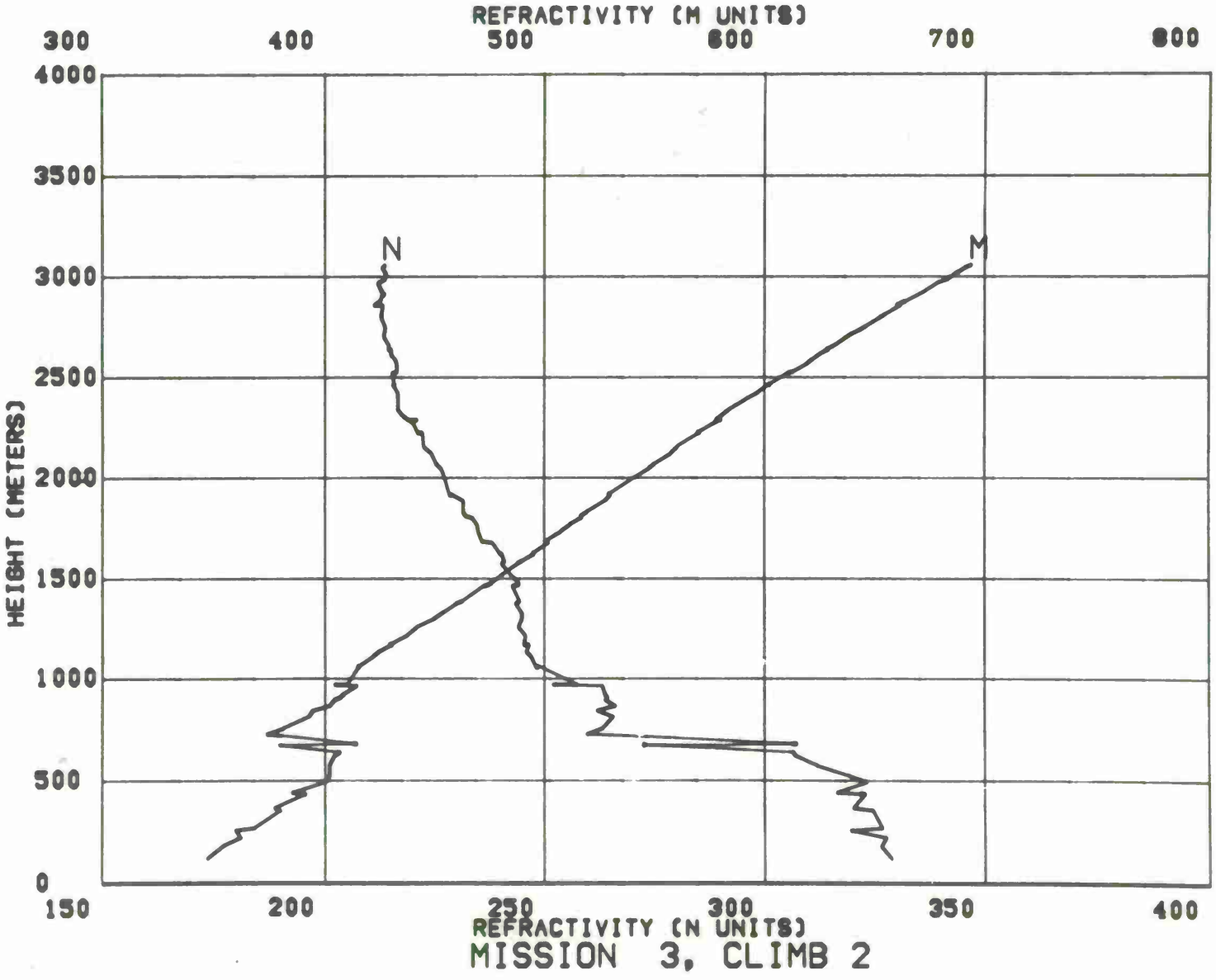
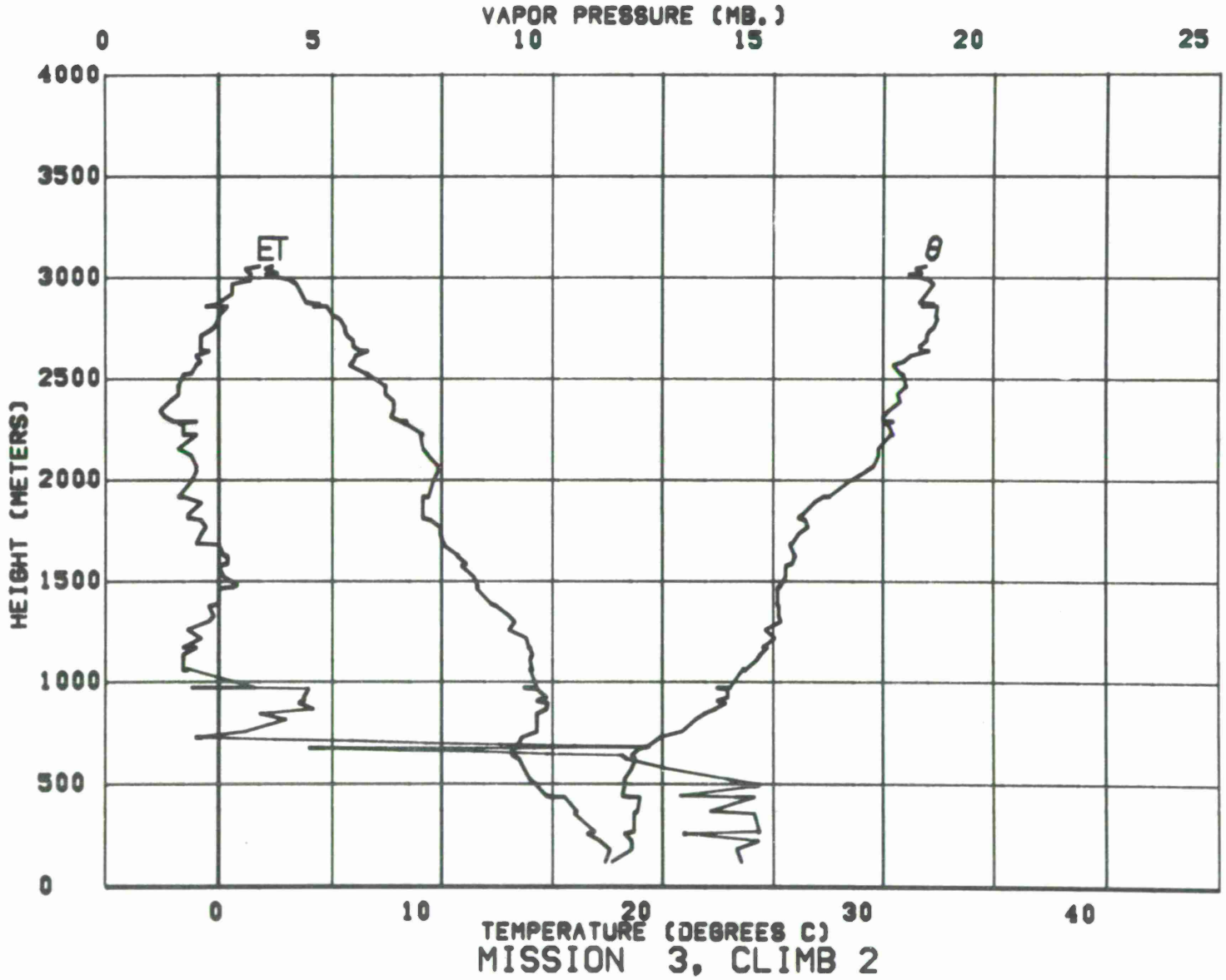
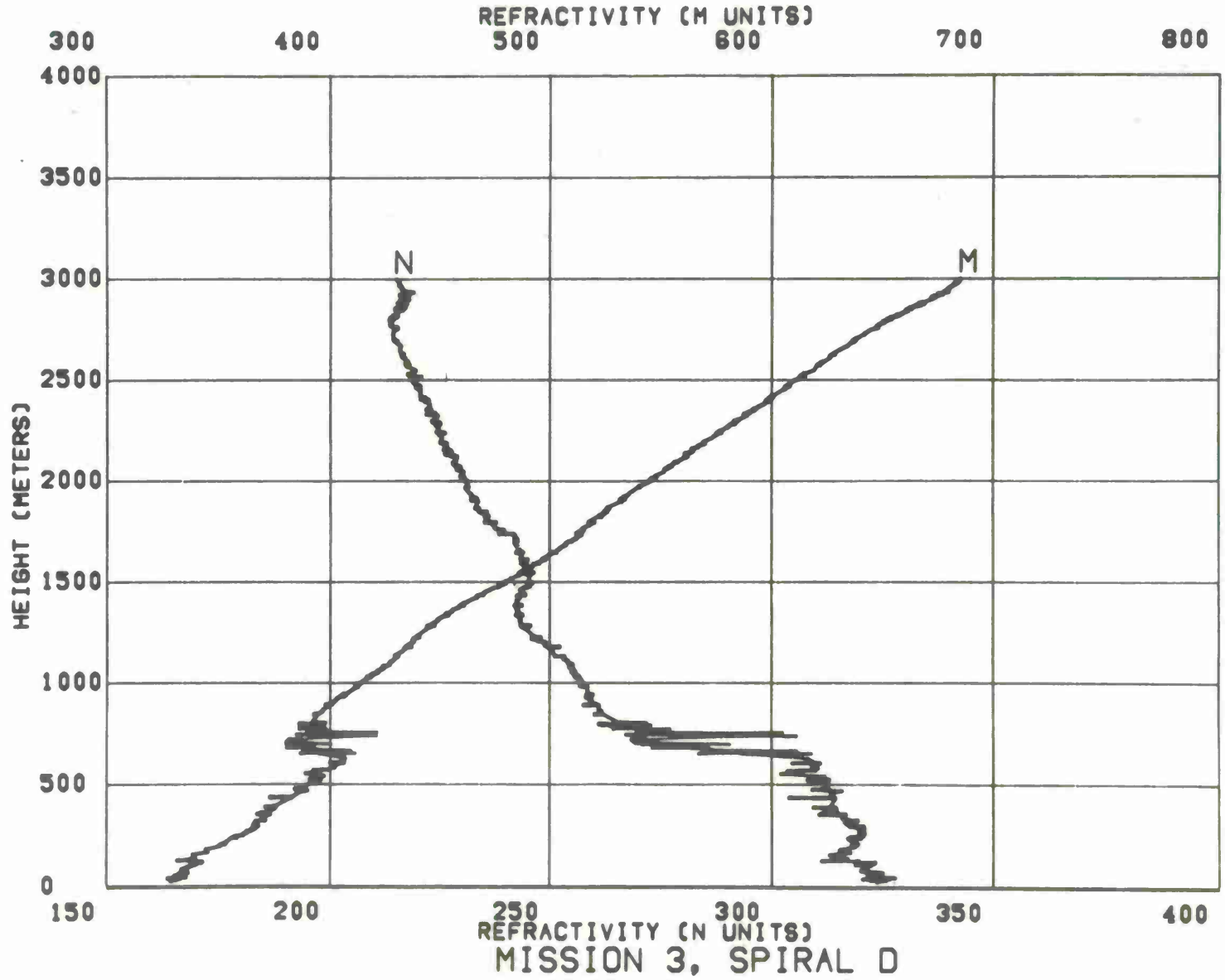
MISSION 3, SPIRAL C



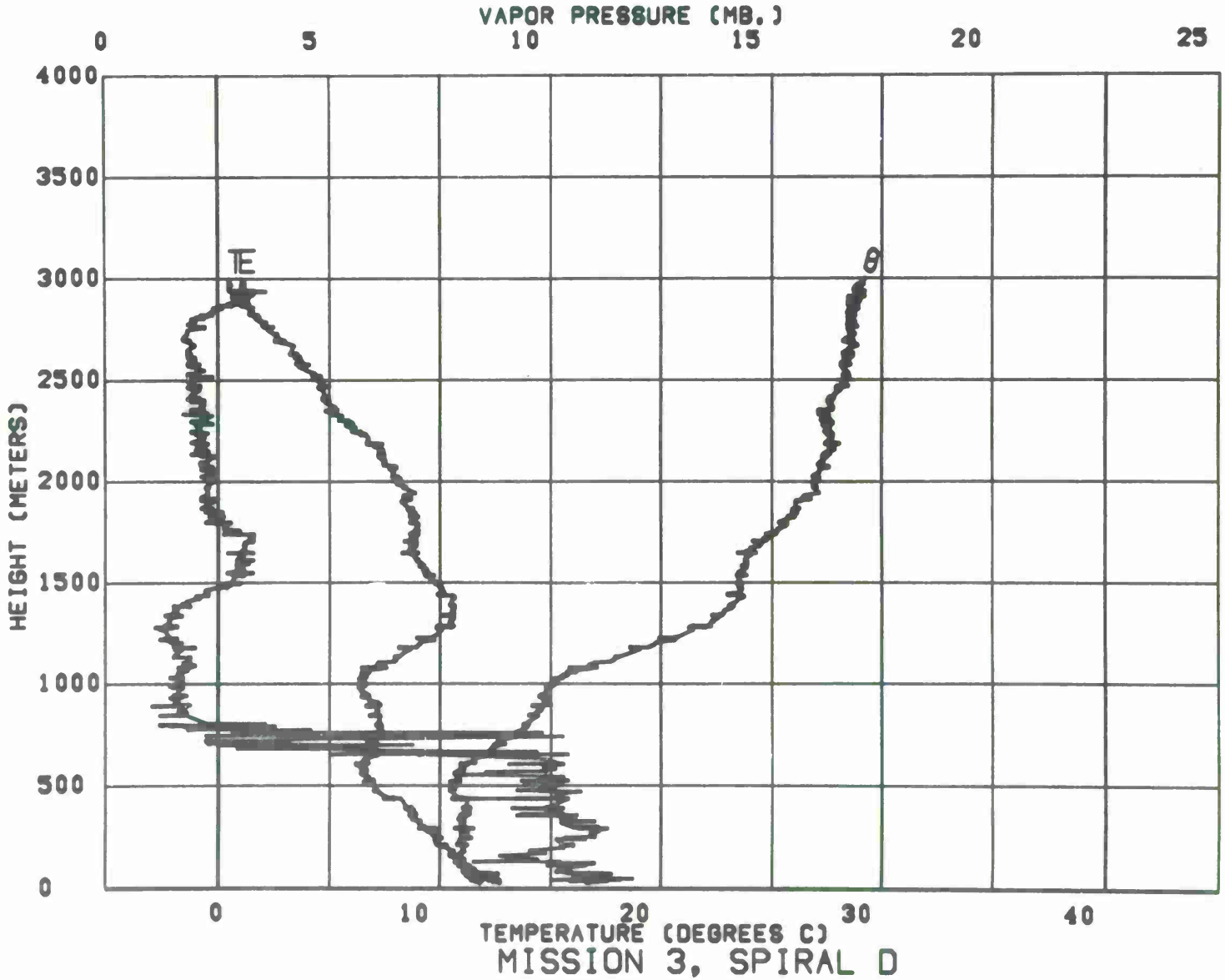
MISSION 3, CLIMB 2



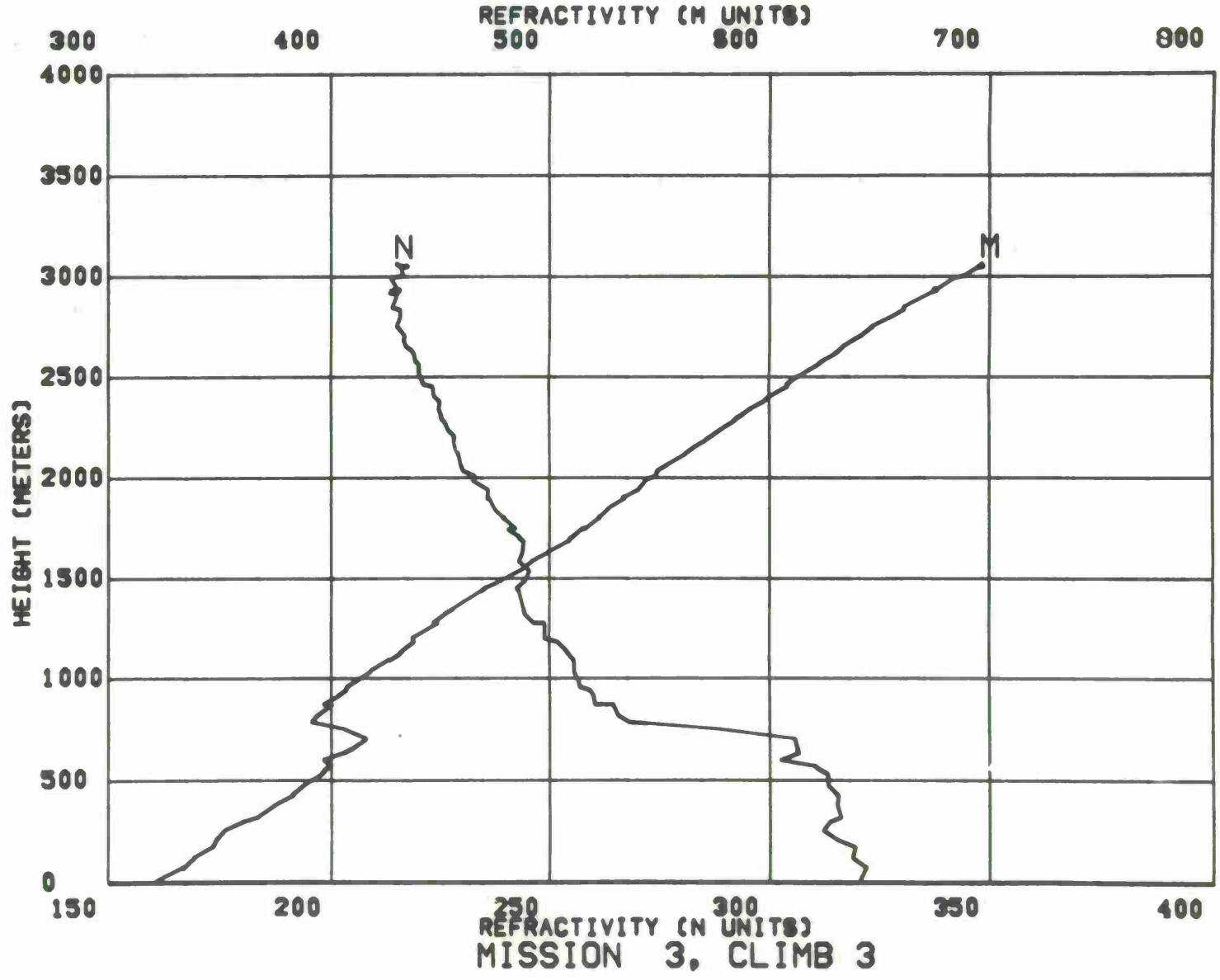
MISSION 3, CLIMB 2



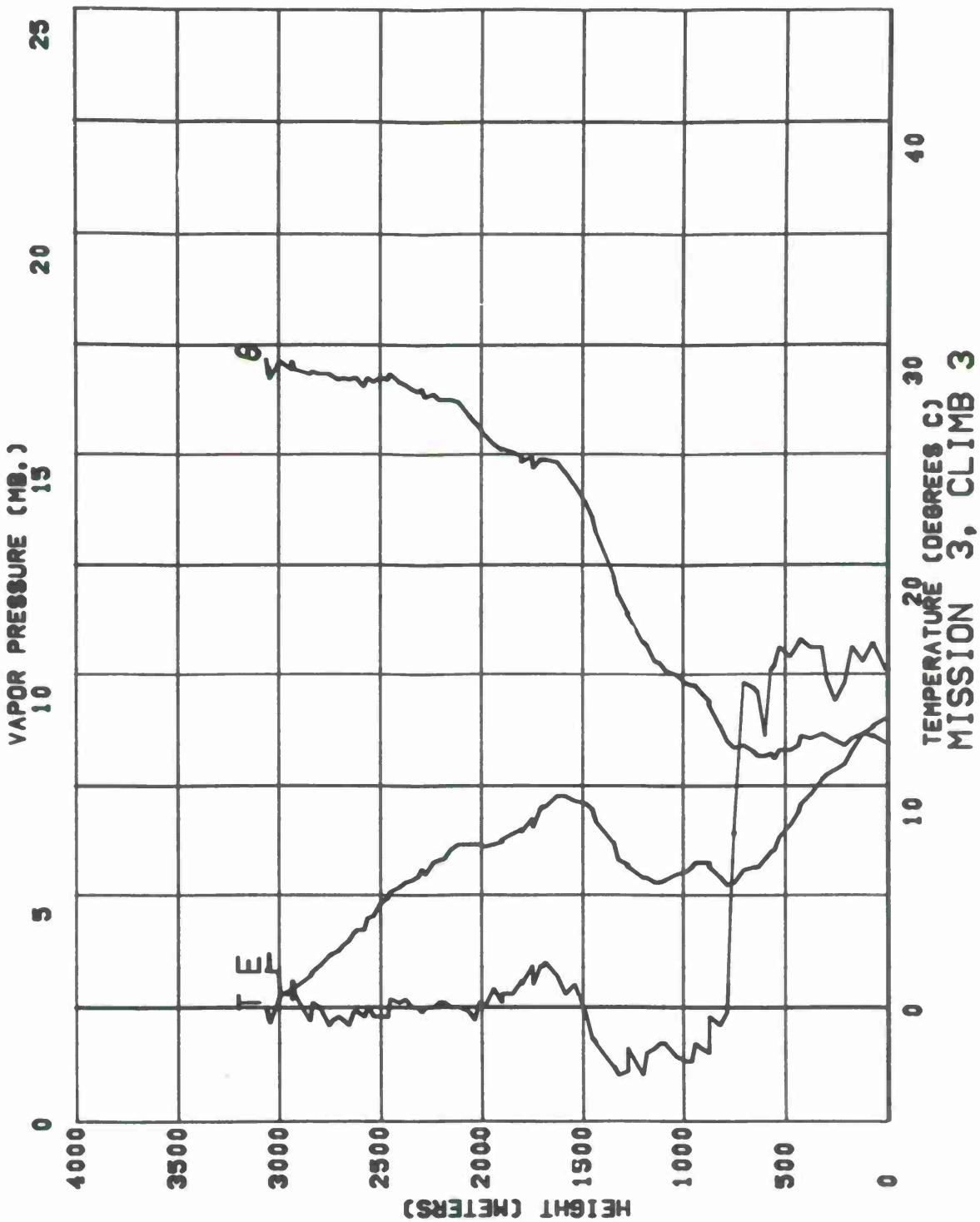
MISSION 3, SPIRAL D



MISSION 3, SPIRAL D



MISSION 3, CLIMB 3


MISSION 3, CLIMB 3
TEMPERATURE (DEGREES C)
VAPOR PRESSURE (MB.)
HEIGHT (METERS)
T
E
L
0
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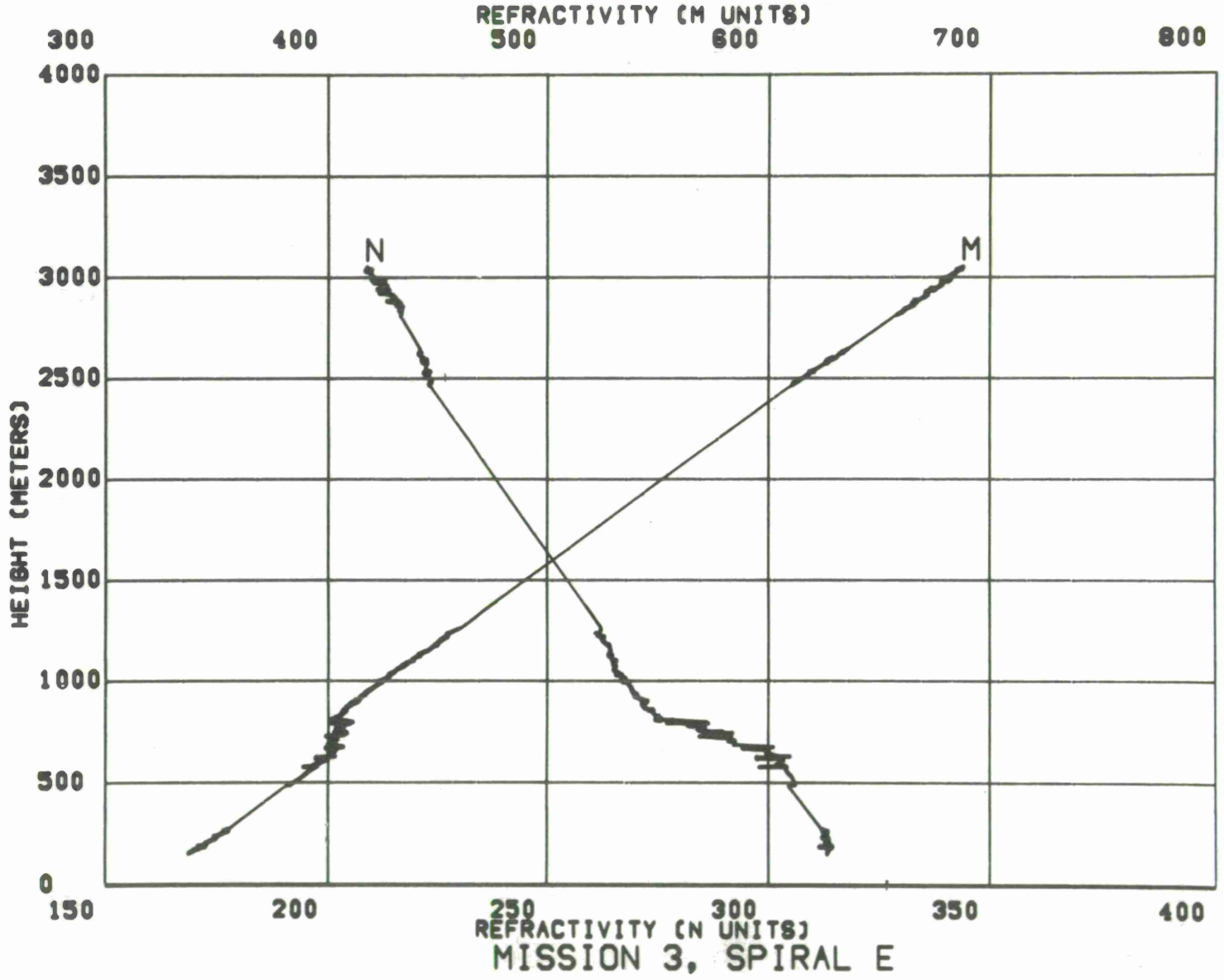
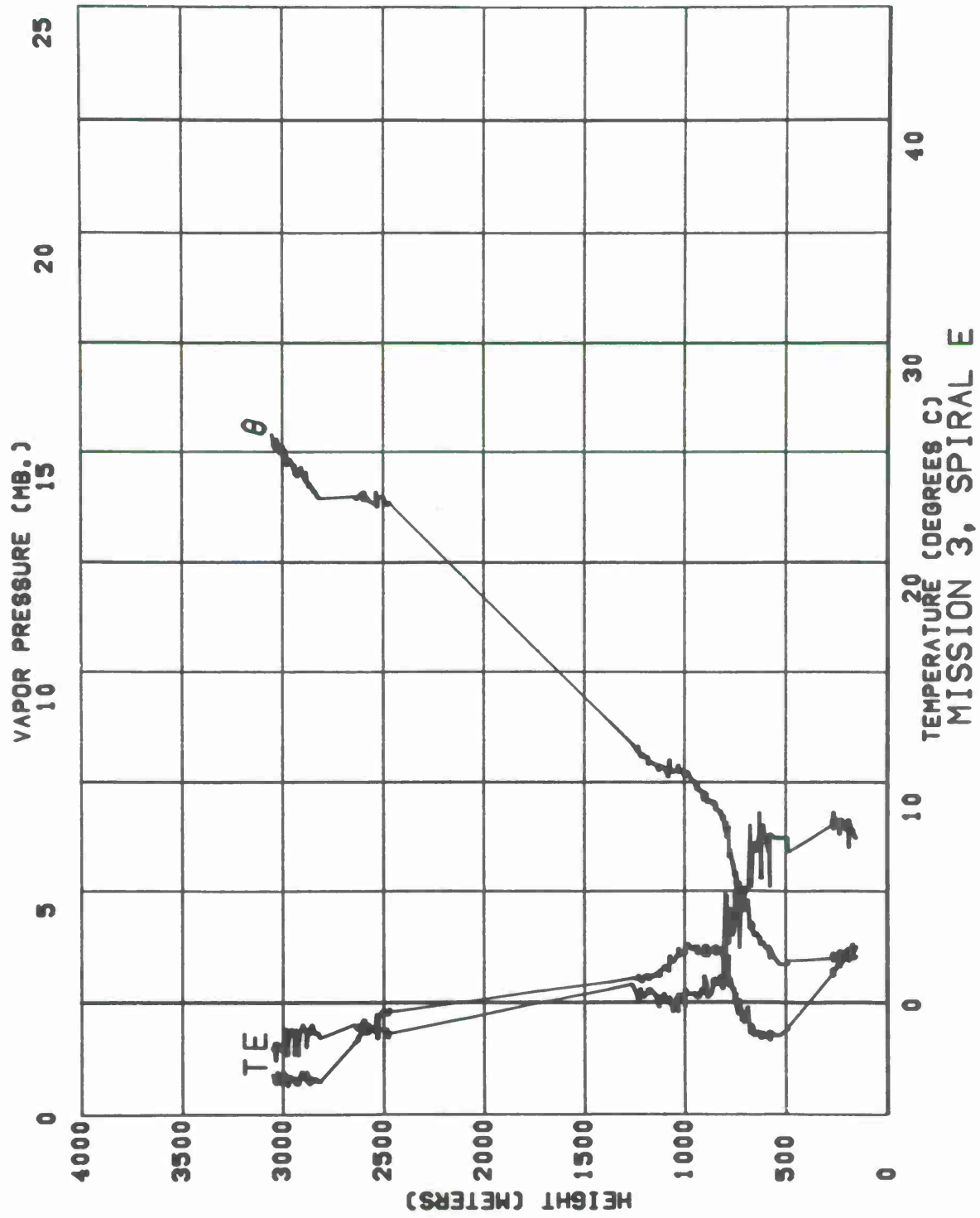
0



MISSION 3, SPIRAL E


VAPOR PRESSURE (MB.)
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HEIGHT (METERS)
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TEMPERATURE (DEGREES C)
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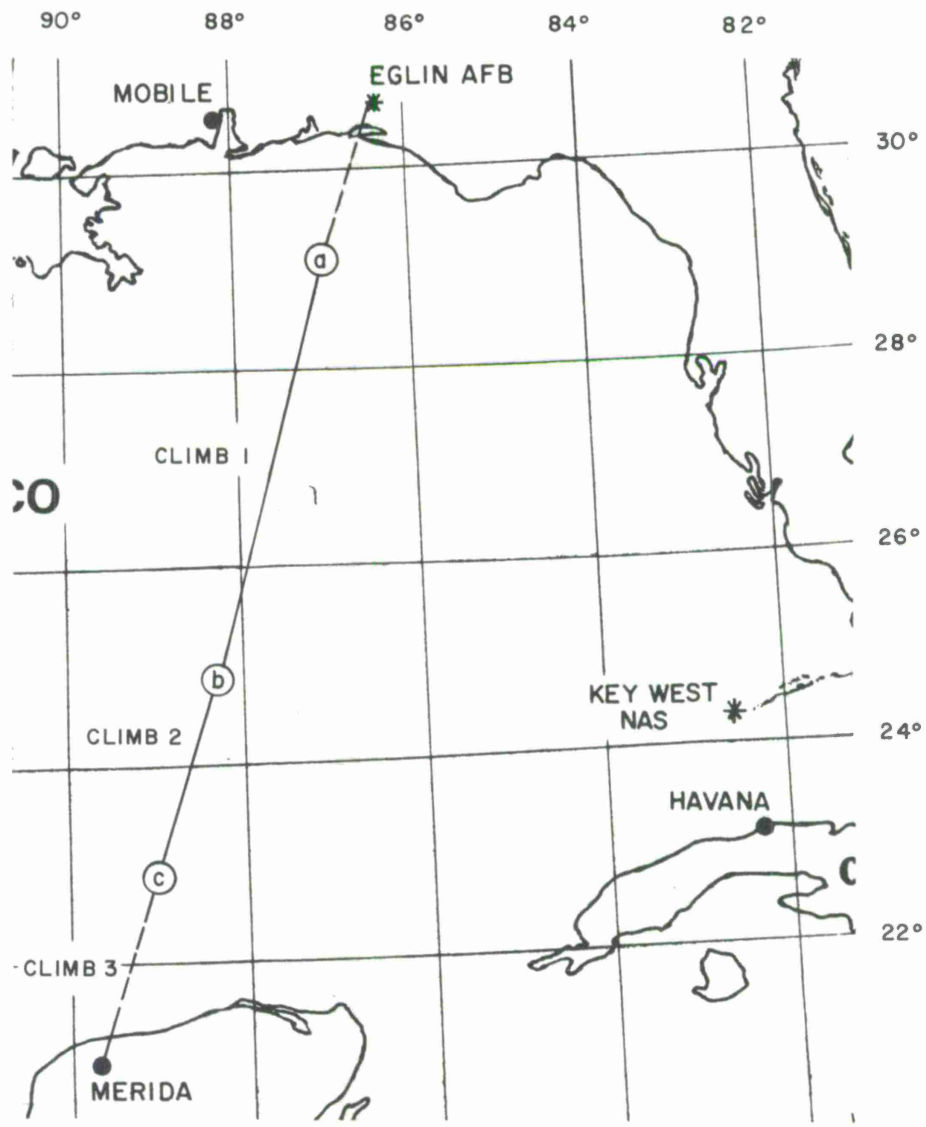
MISSION 3, SPIRAL E

MISSION NO. 4

Date: 10 March 1969

Data were obtained along Flight Path III, from Eglin AFB to Merida, Mexico. Measurements were recorded during three spirals and two ascents, the limitation on number of spirals arising from a combination of two factors: (1) delayed start of mission, (2) need to land at Merida before nightfall.

Spiral	Location	Spiral Start Time Z	Local
A	a. 29-00 N, 87-00 W	2032	1432
Climb 1	a-b	2050	1450
B	b. 25-00 N, 88-13 W	2217	1617
Climb 2	b-c	2235	1635
C	c. 23-00 N, 89-00 W	2315	1715
Climb 3			



SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300

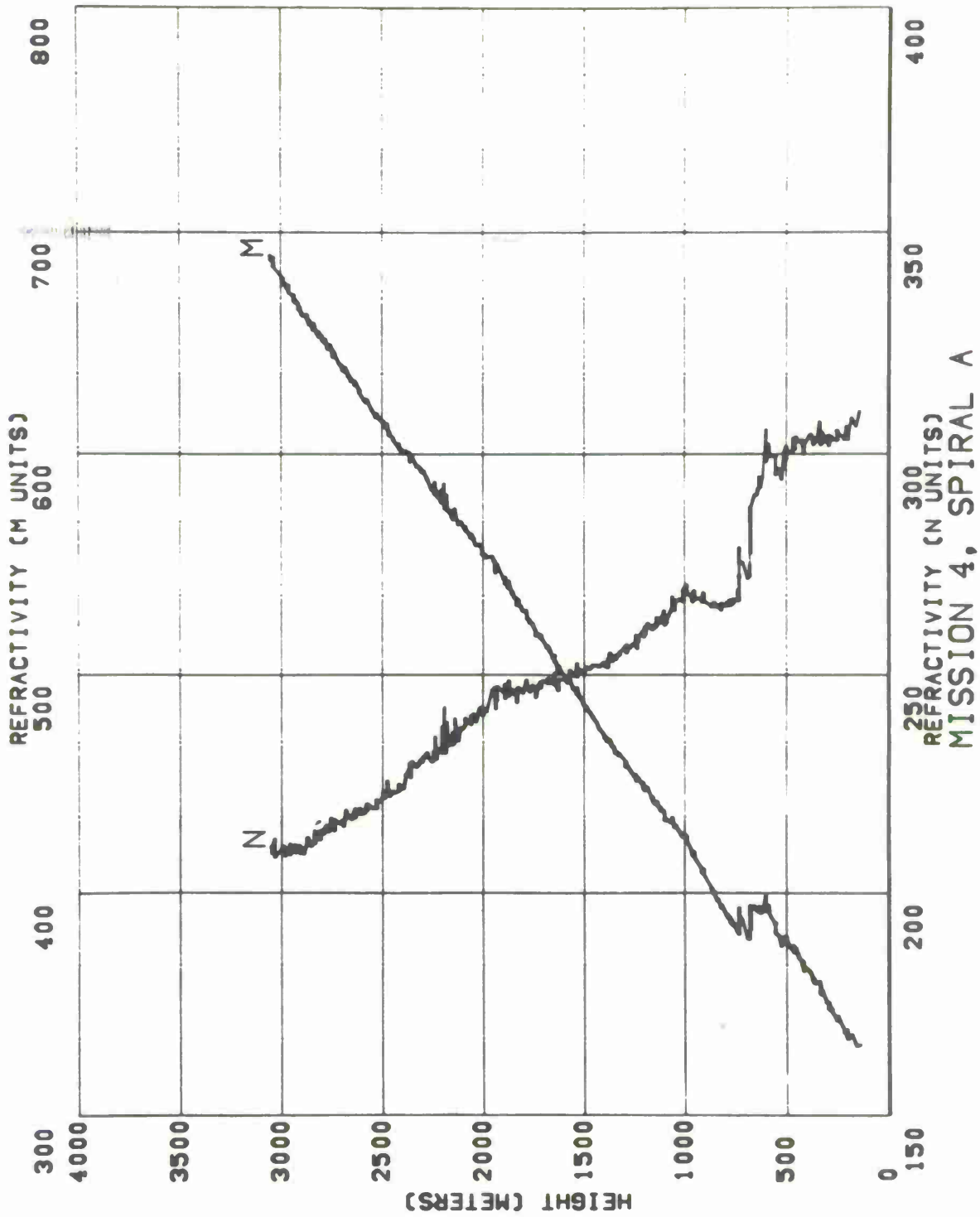
STATUTE MILES

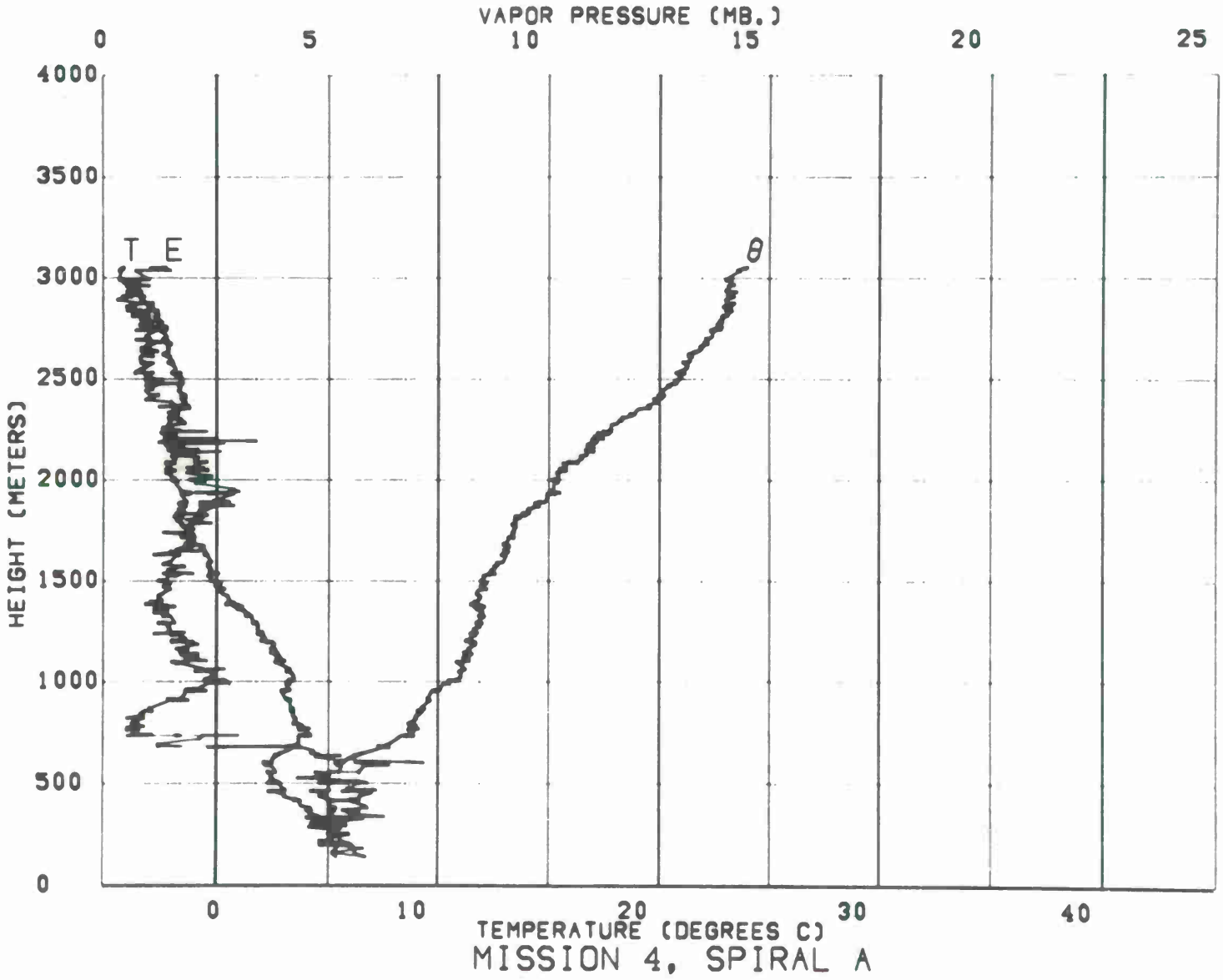
100 50 0 100 200 300 400

KILOMETERS

FLIGHT PATH III

MISSION 4 — 10 MARCH 1969


MISSION 4, SPIRAL A
REFRACTIVITY (M UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
M
N
800
700
600
500
400
300
400
350
300
250
200
150
4000
3500
3000
2500
2000
1500
1000
500
0


VAPOR PRESSURE (MB.)
0
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10
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20
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4000
3500
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2000
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1000
500
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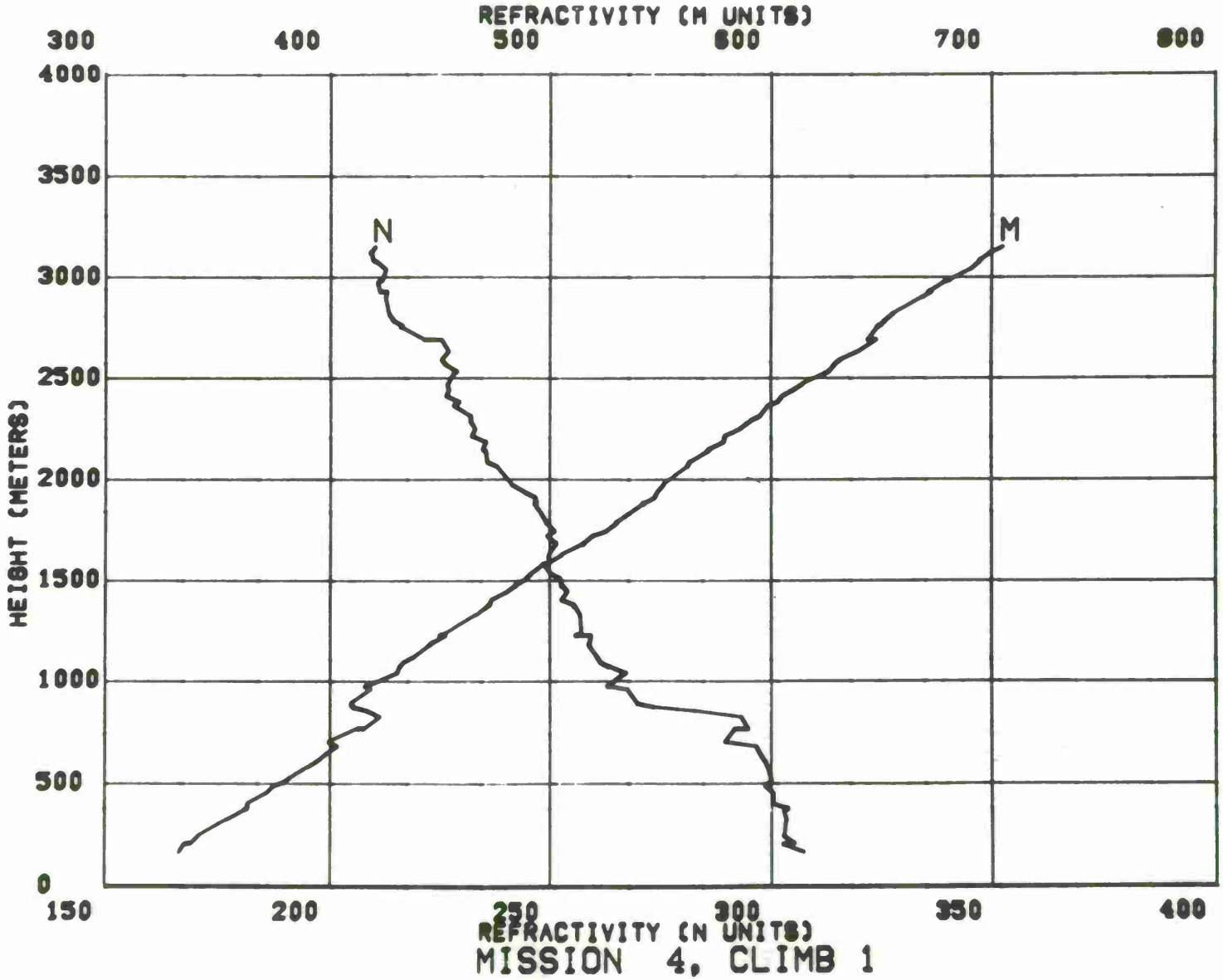
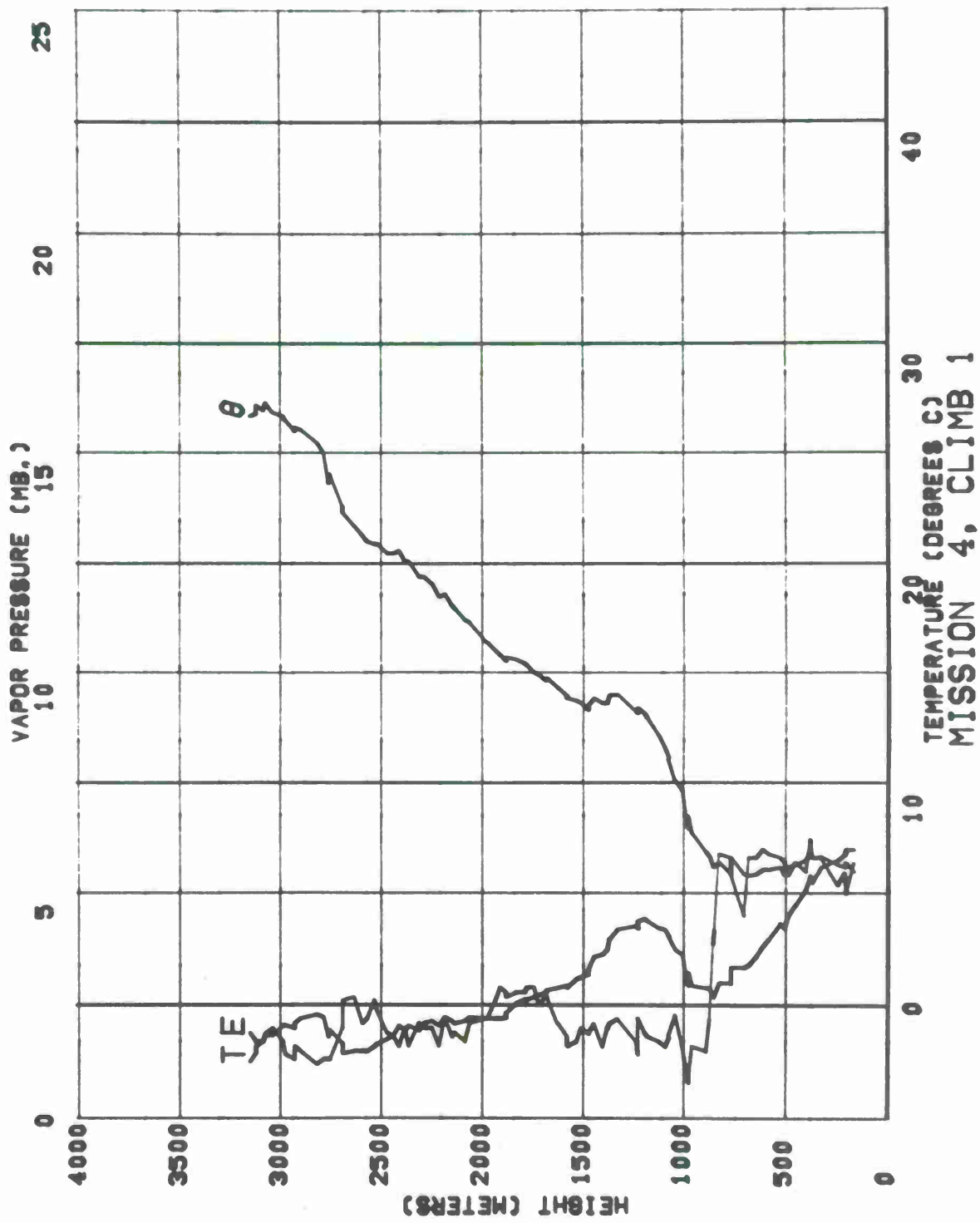
T E
θ
HEIGHT (METERS)
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 4, SPIRAL A



MISSION 4, CLIMB 1


VAPOR PRESSURE (MB.)
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25
HEIGHT (METERS)
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3500
3000
2500
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500
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TEMPERATURE (DEGREES C)
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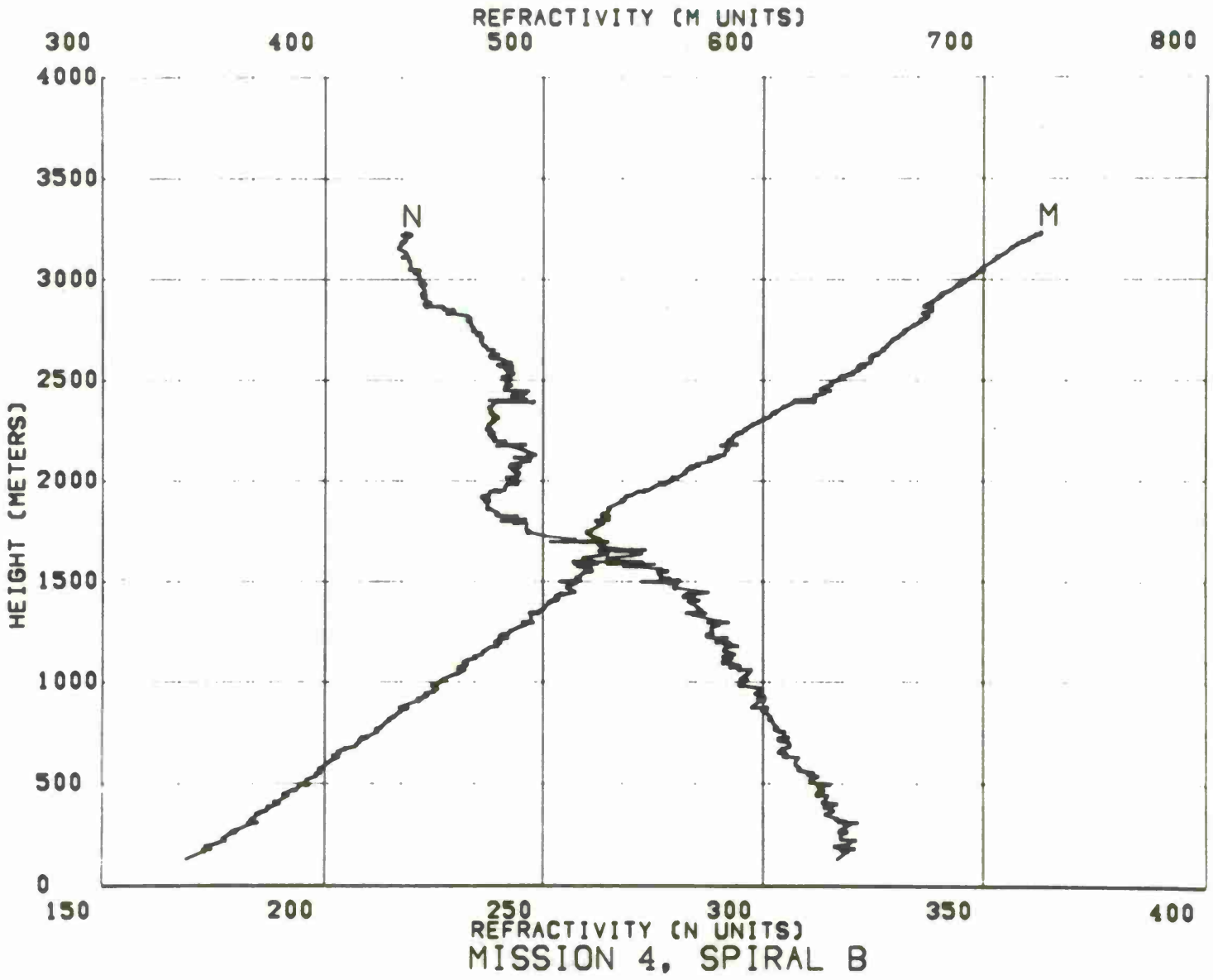
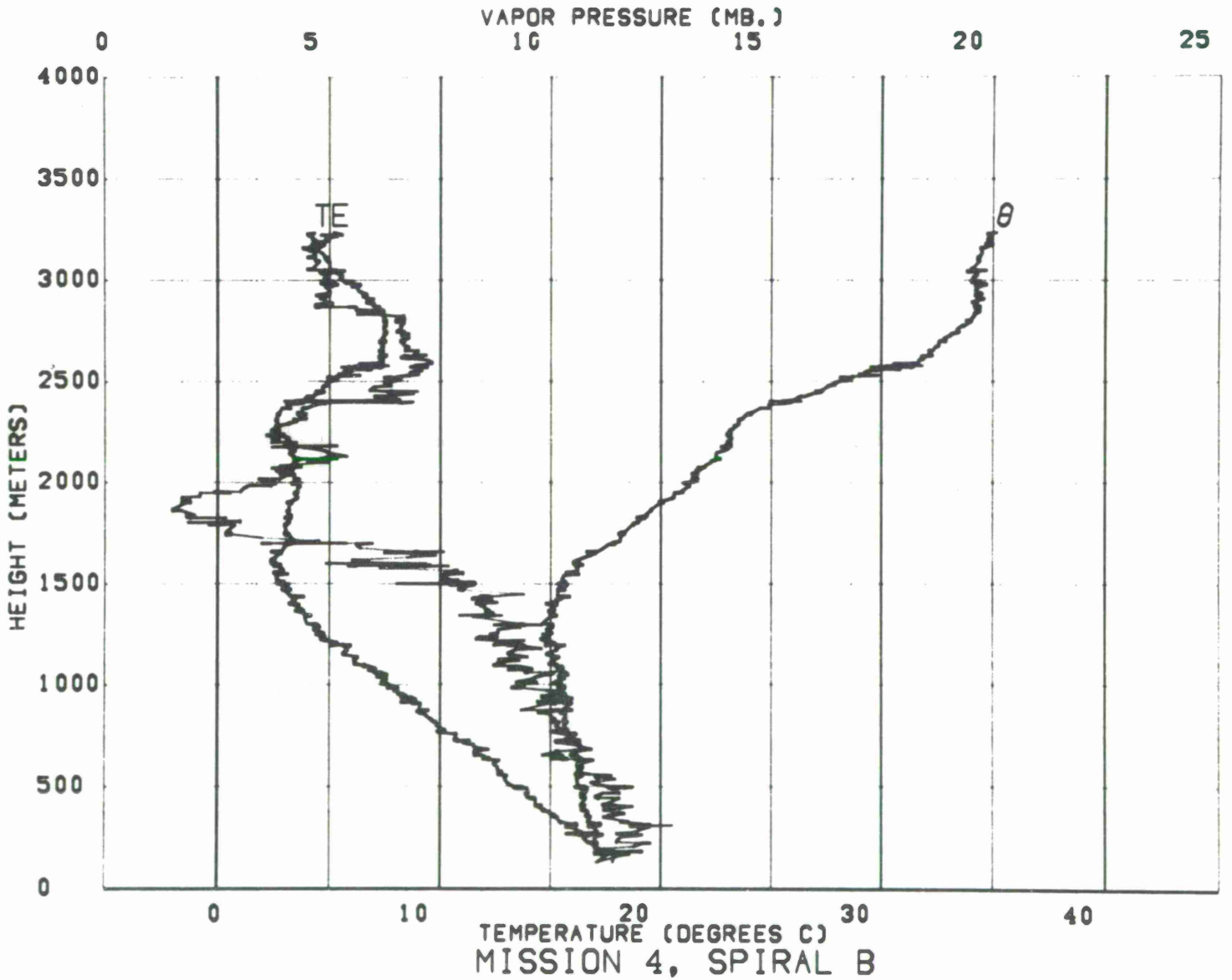
MISSION 4, CLIMB 1


REFRACTIVITY (M UNITS)
300
400
500
600
700
800
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
N
M
150
200
250
300
350
400
REFRACTIVITY (N UNITS)
MISSION 4, SPIRAL B


VAPOR PRESSURE (MB.)
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HEIGHT (METERS)
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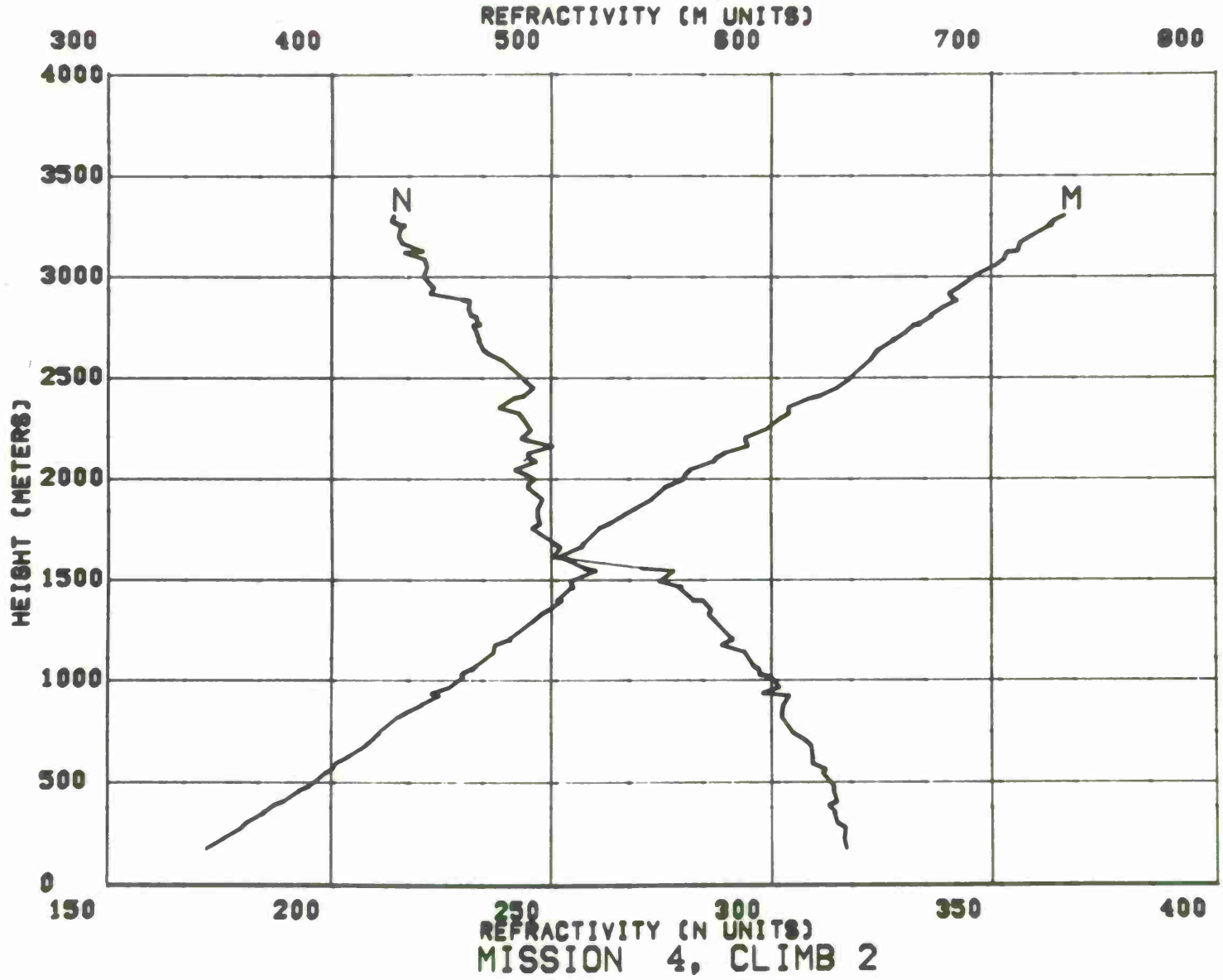
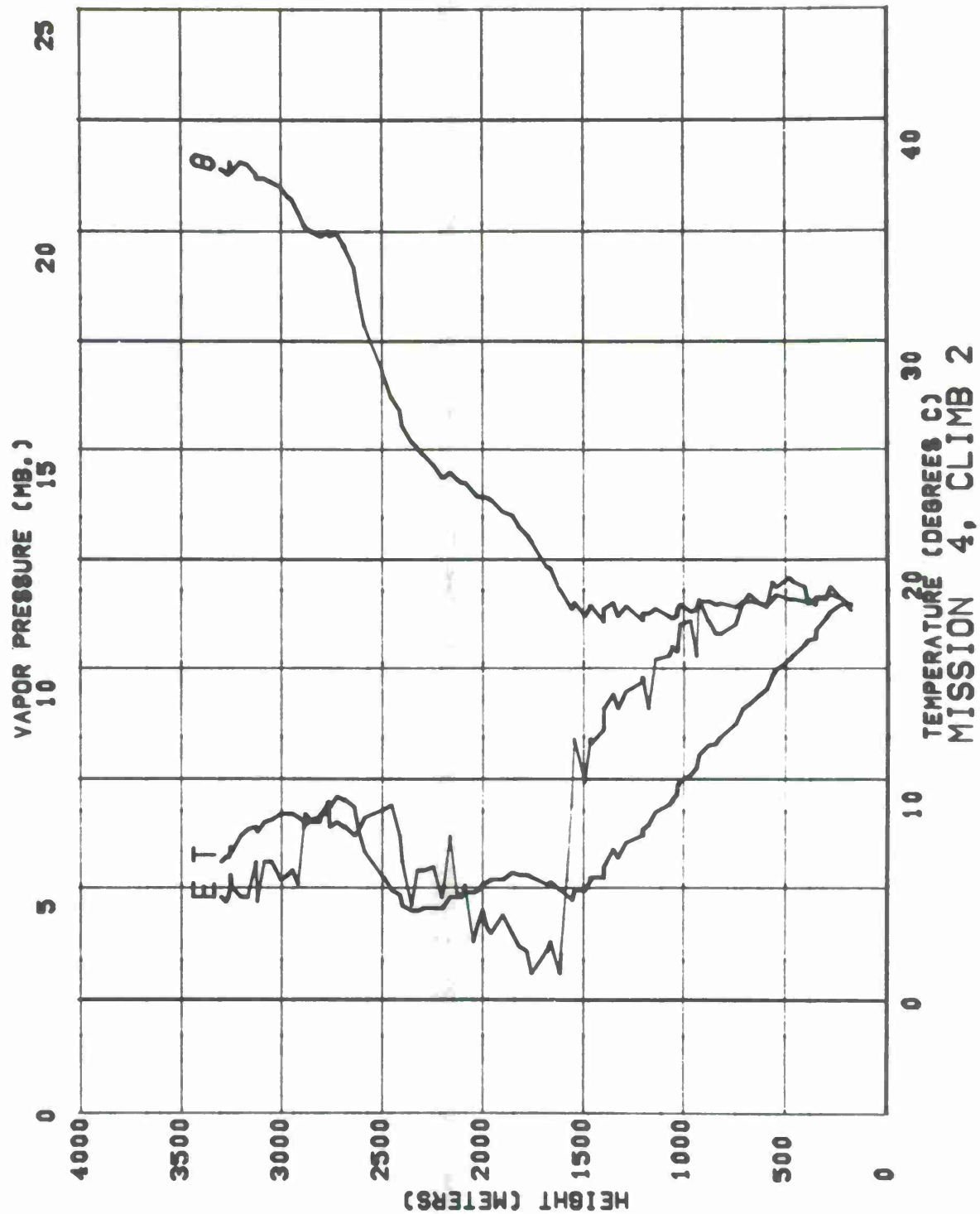
TEMPERATURE (DEGREES C)
MISSION 4, SPIRAL B



MISSION 4, CLIMB 2


MISSION 4, CLIMB 2
VAPOR PRESSURE (MB.)
TEMPERATURE (DEGREES C)
HEIGHT (METERS)
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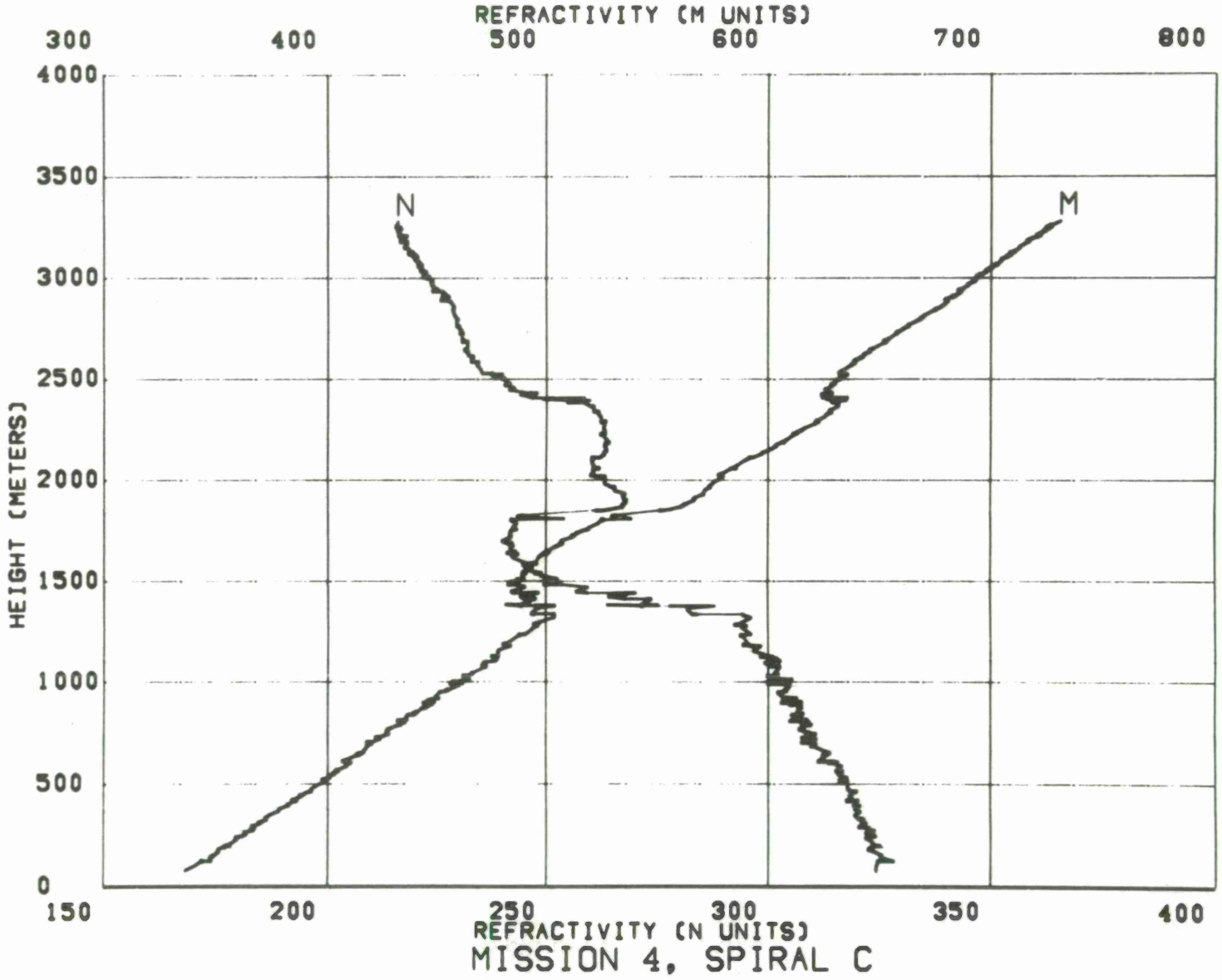
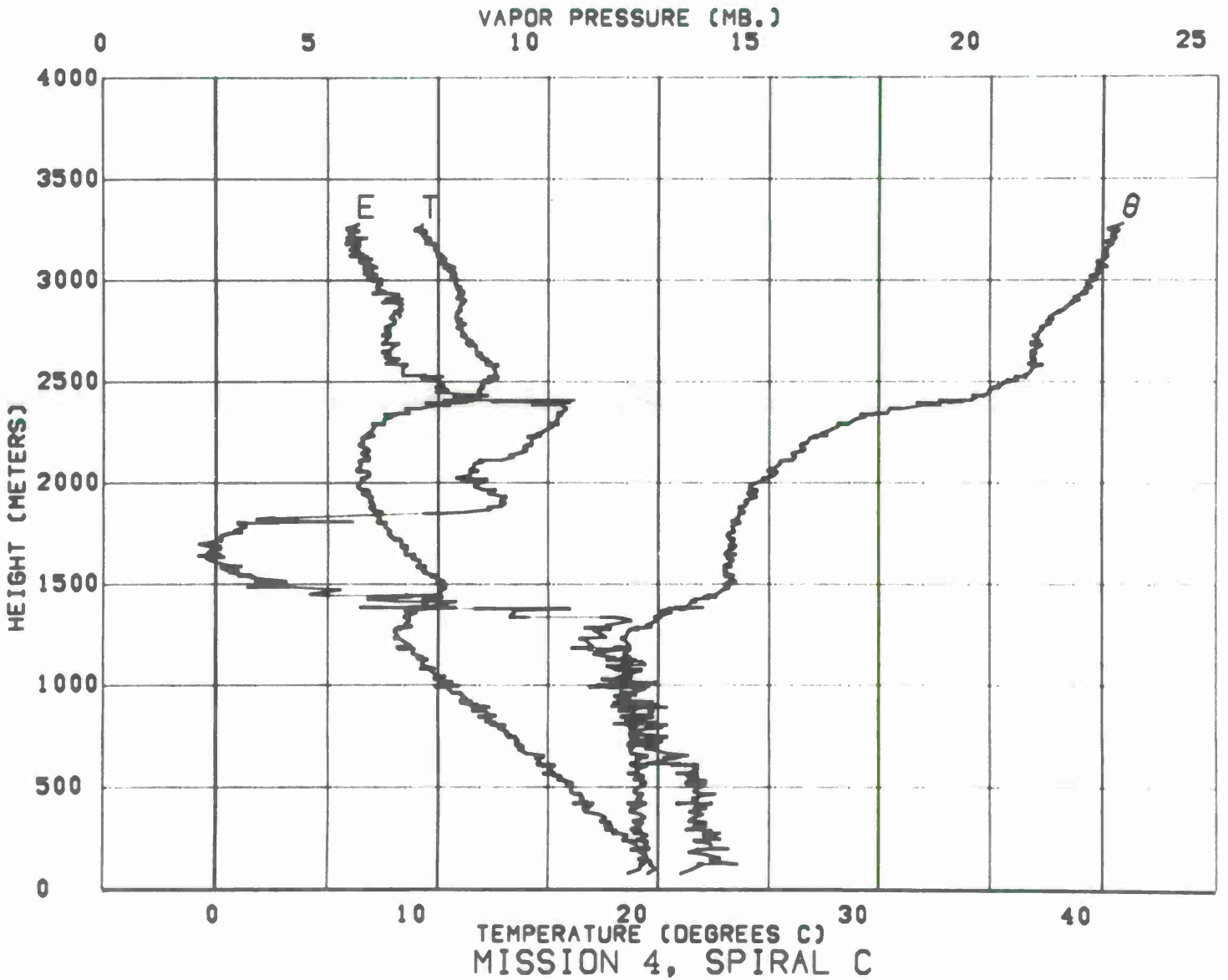


MISSION 4, SPIRAL C


VAPOR PRESSURE (MB.)
0
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10
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4000
3500
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2000
1500
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HEIGHT (METERS)
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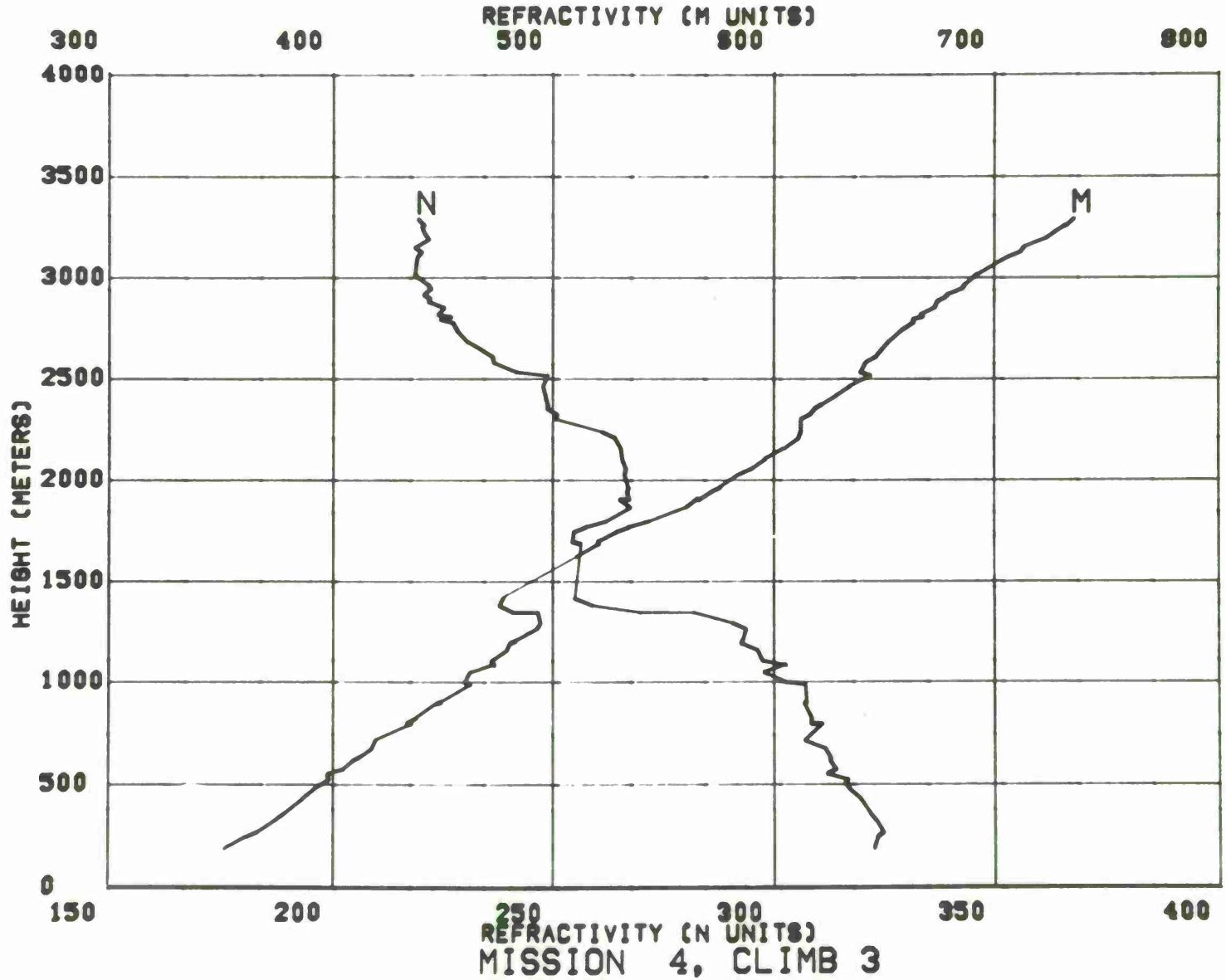
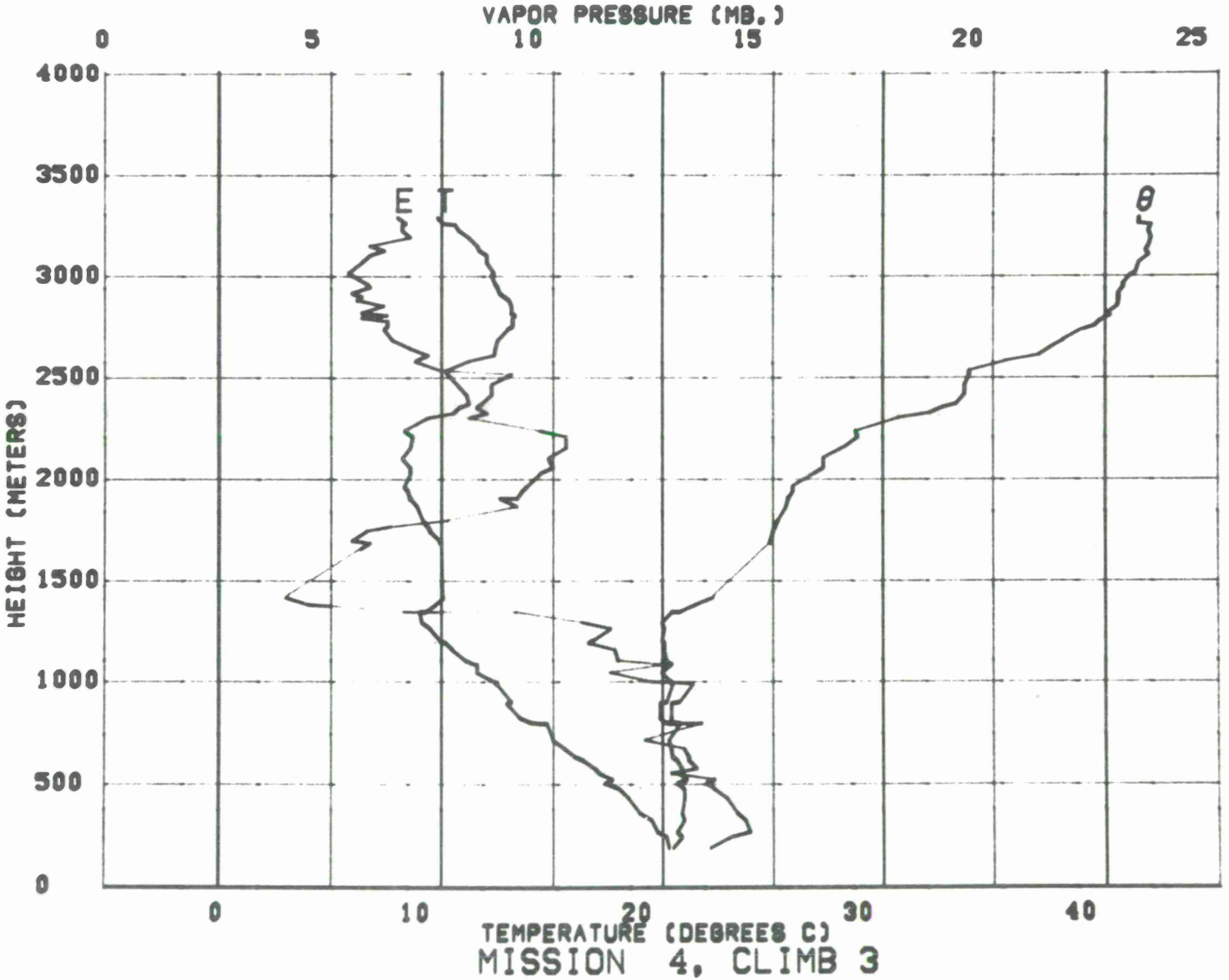
T
θ
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 4, SPIRAL C



MISSION 4, CLIMB 3



MISSION 4, CLIMB 3

MISSION NO. 5

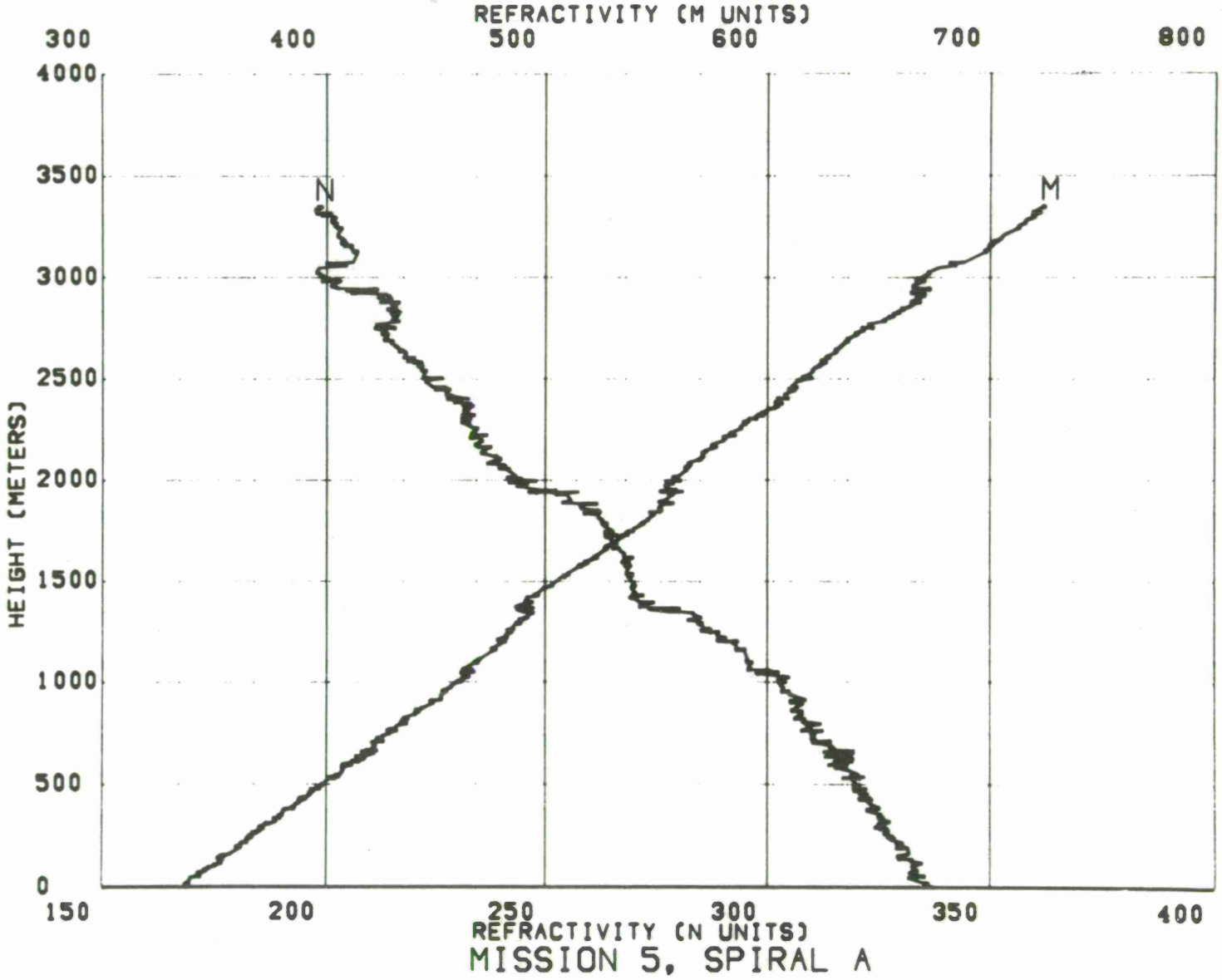
Date: 11 March 1969

Data were obtained on four spirals and two ascents along Flight Path IV, from Merida, Mexico, to Georgetown, Cayman Islands.

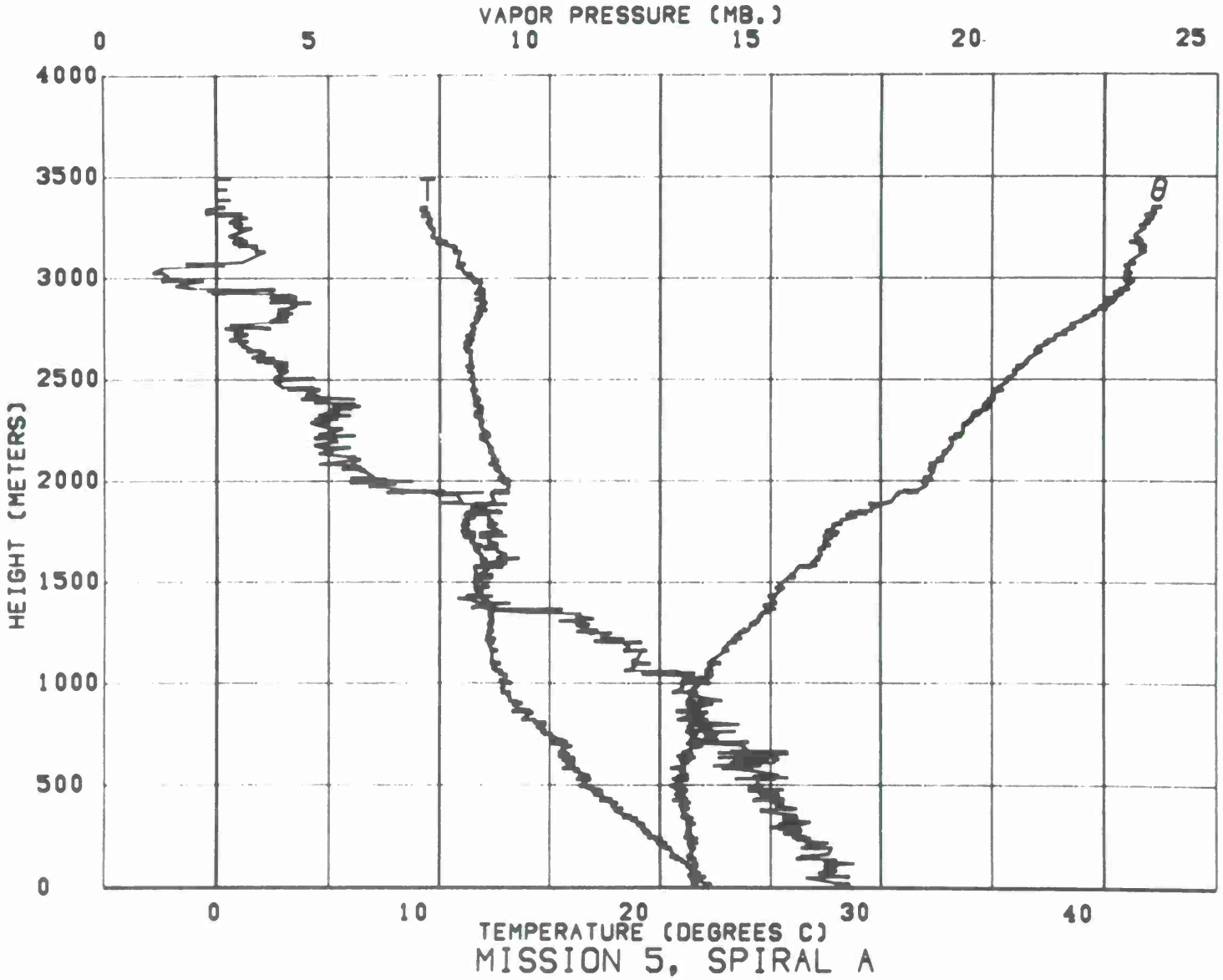
Spiral	Location	Spiral Start Time Z	Local
A	a. 20-00 N, 86-25 W	1848	1248
Climb 1	a-b	1908	1308
B	b. 19-00 N, 85-35 W	1935	1335
Climb 2	b-c	1958	1358
C	c. 18-30 N, 84-00 W	2030	1430
Climb 3			
D	d. 19-15 N, 81-15 W	2150	1550

FLIGHT PATH IV

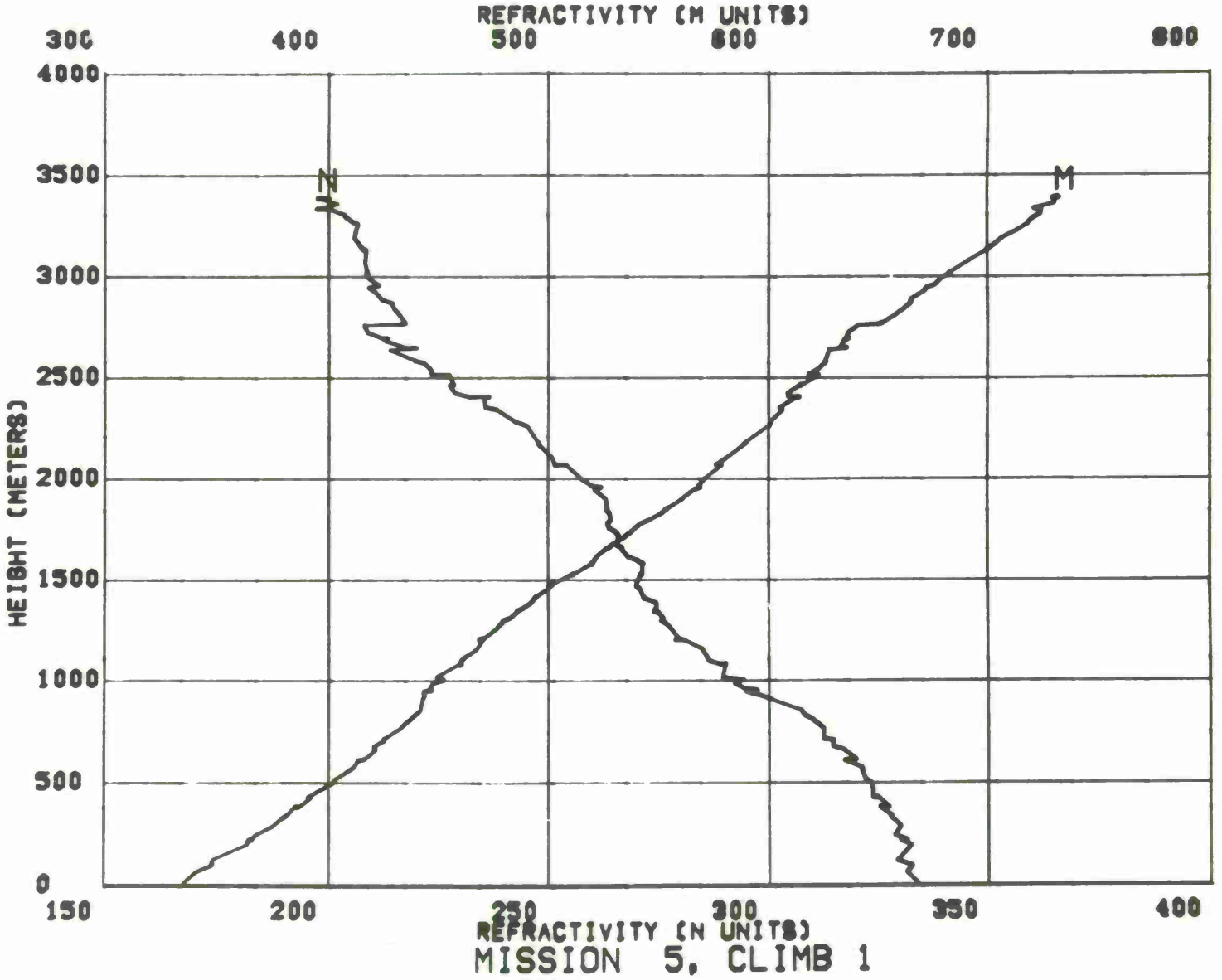
MISSION 5 — 11 MARCH 1969



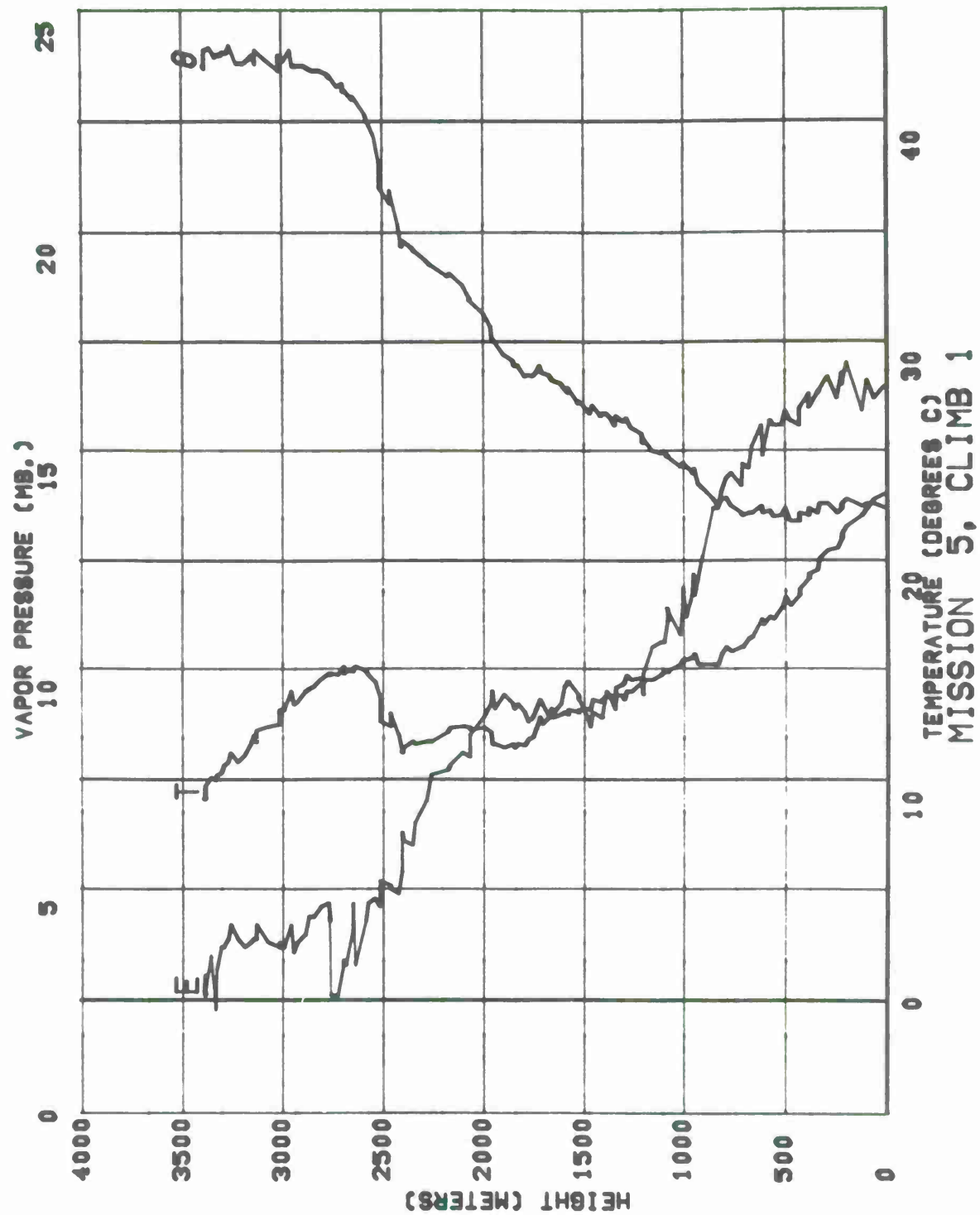
MISSION 5, SPIRAL A



MISSION 5, SPIRAL A



MISSION 5, CLIMB 1


MISSION 5, CLIMB 1
VAPOR PRESSURE (MB.)
TEMPERATURE (DEGREES C)
HEIGHT (METERS)
0
5
10
15
20
25
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10
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4000
3500
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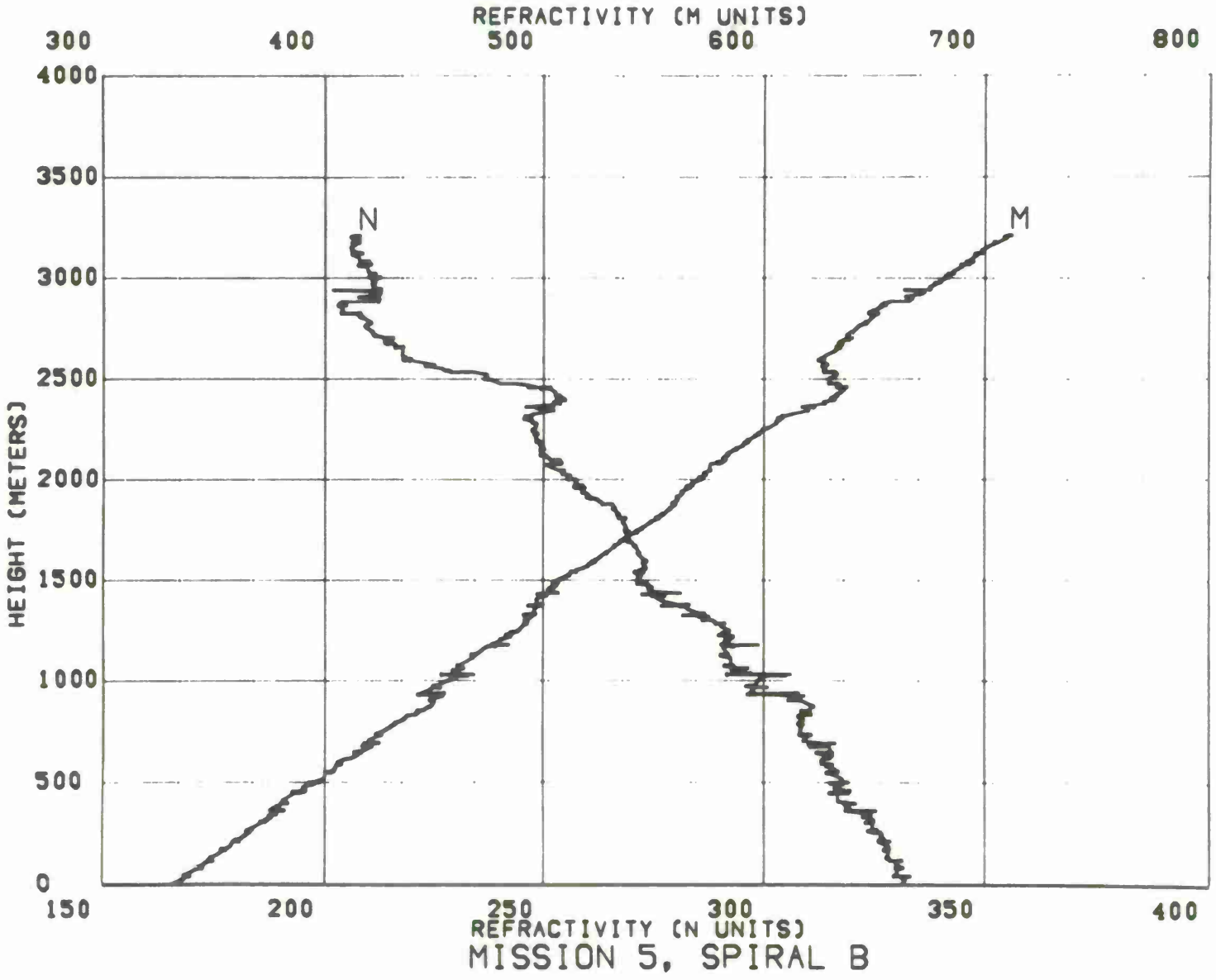
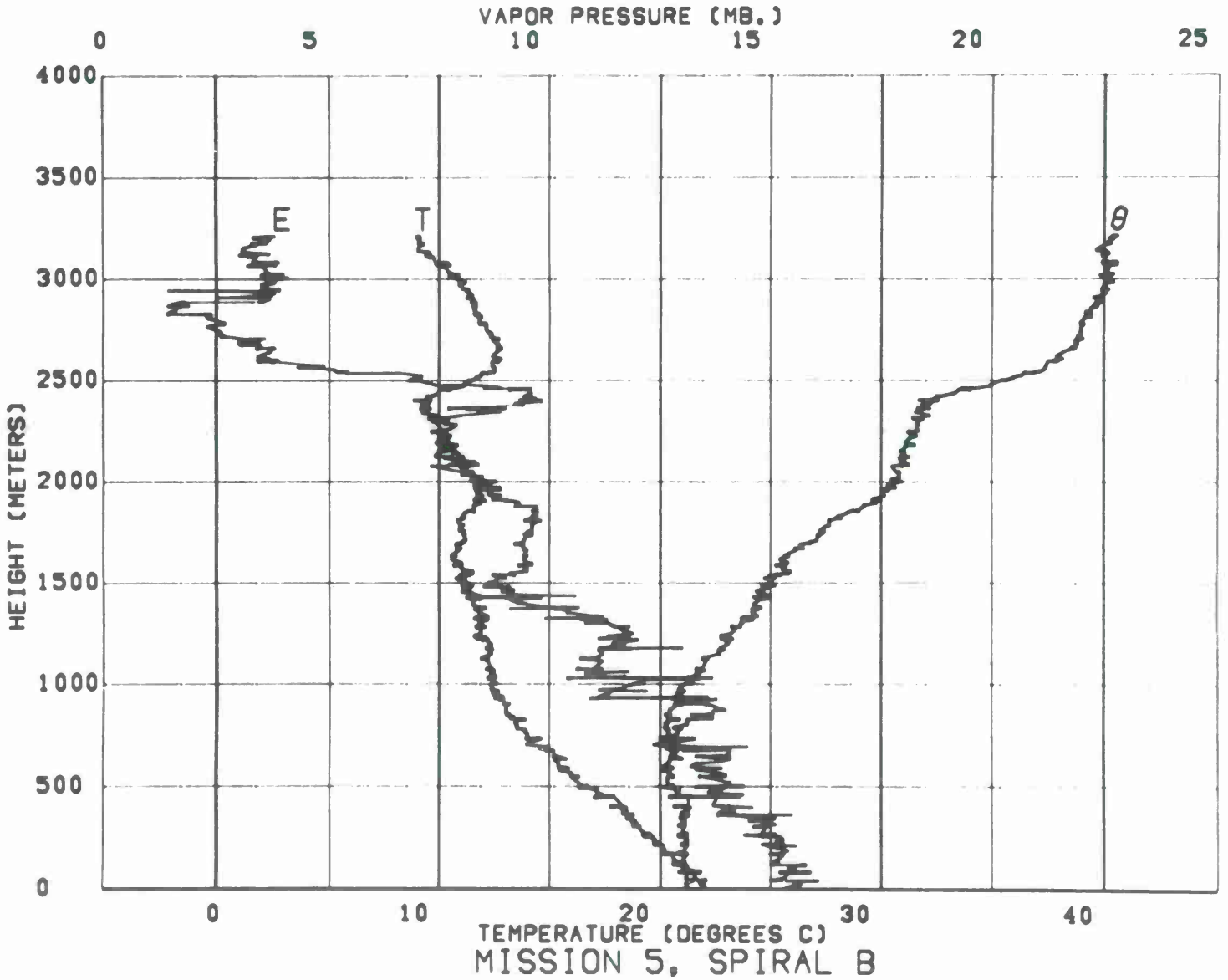
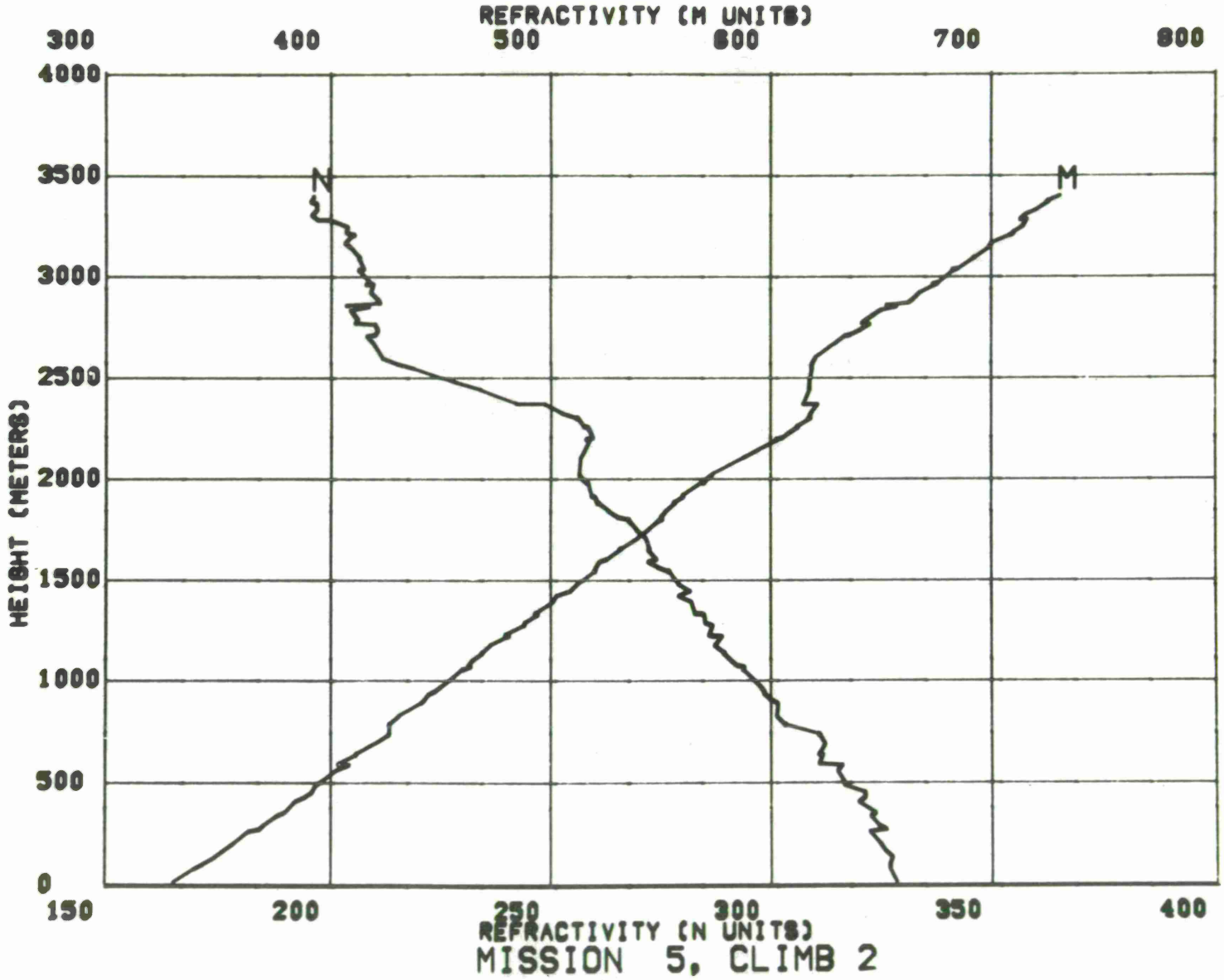


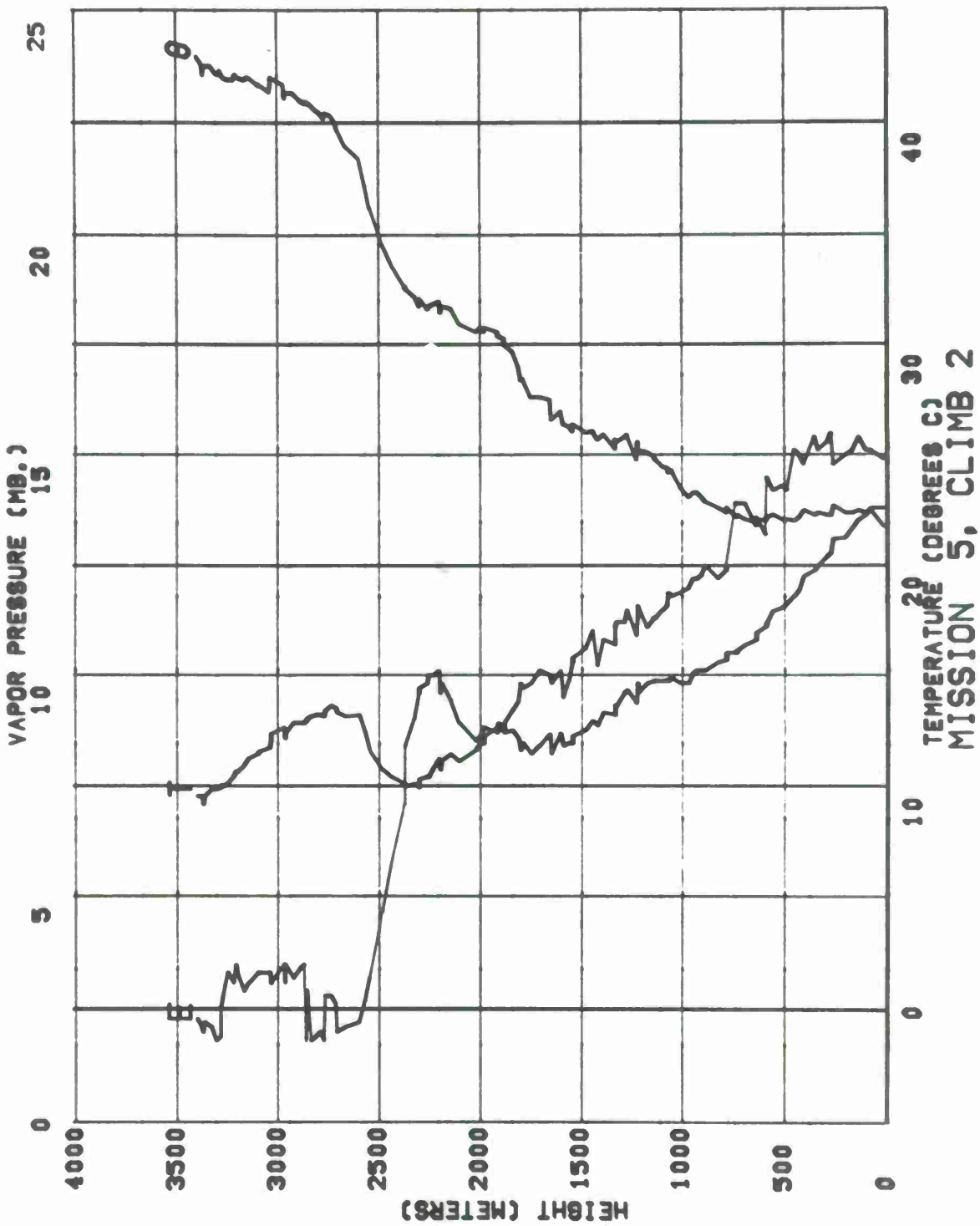
MISSION 5, SPIRAL B

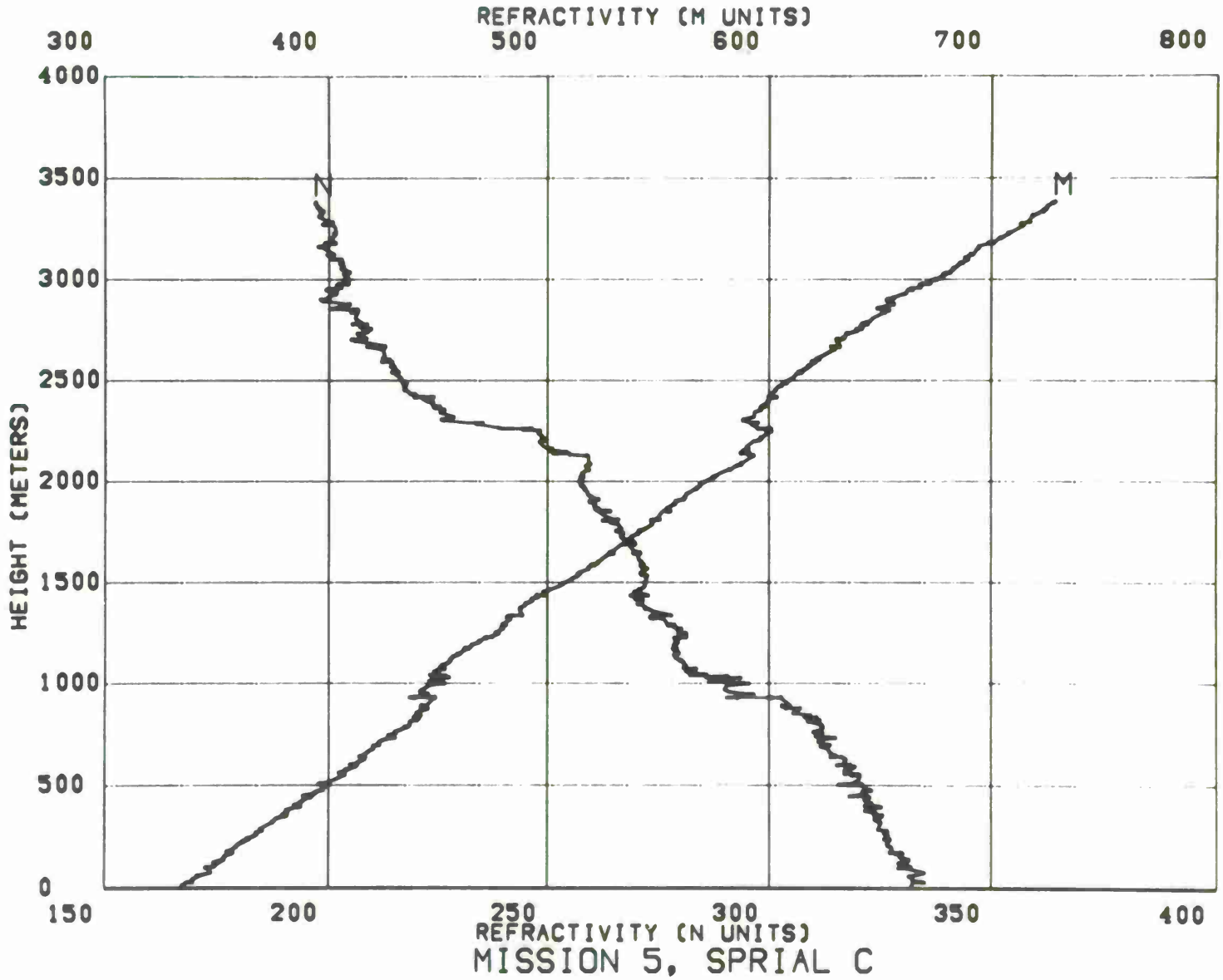


MISSION 5, SPIRAL B

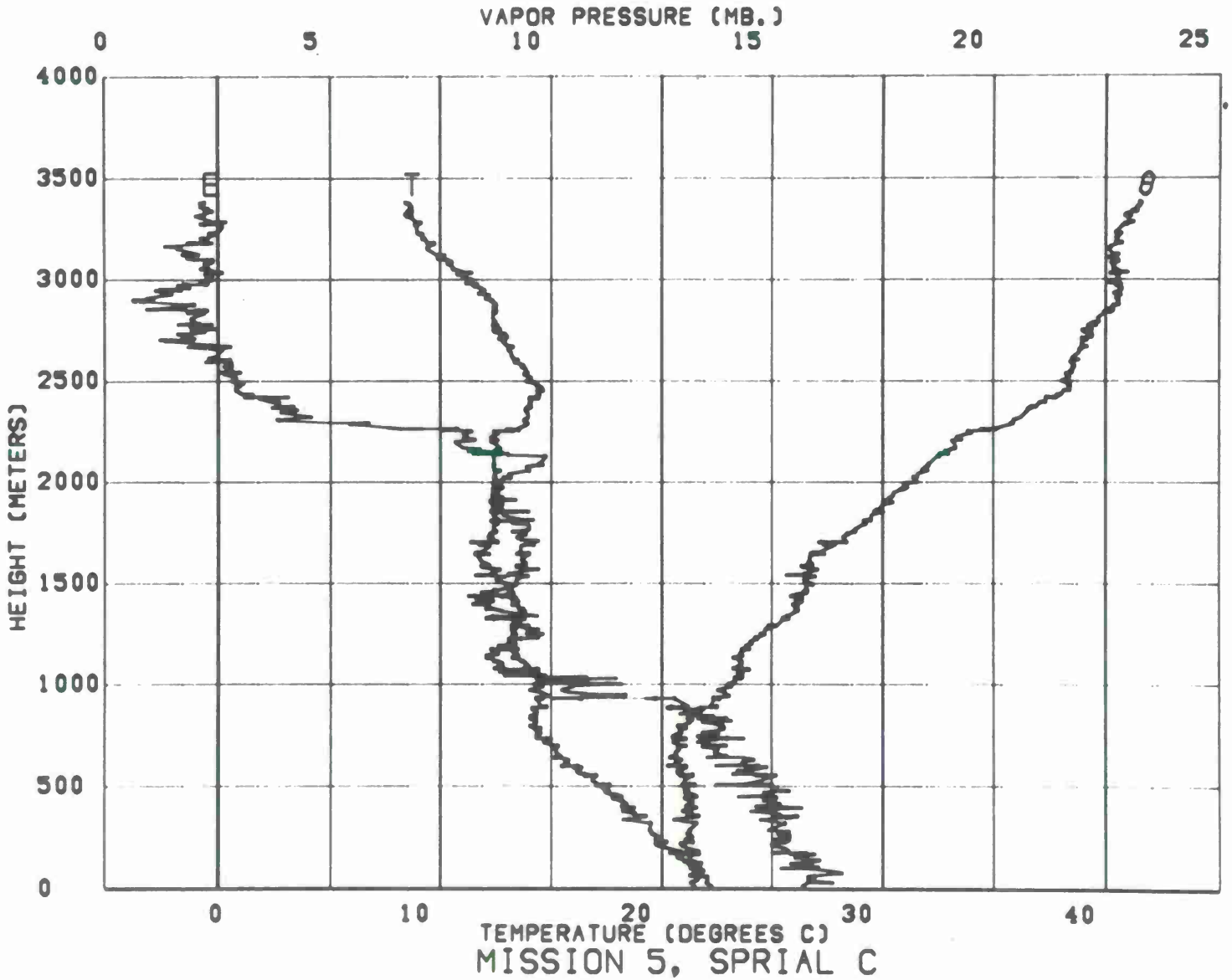


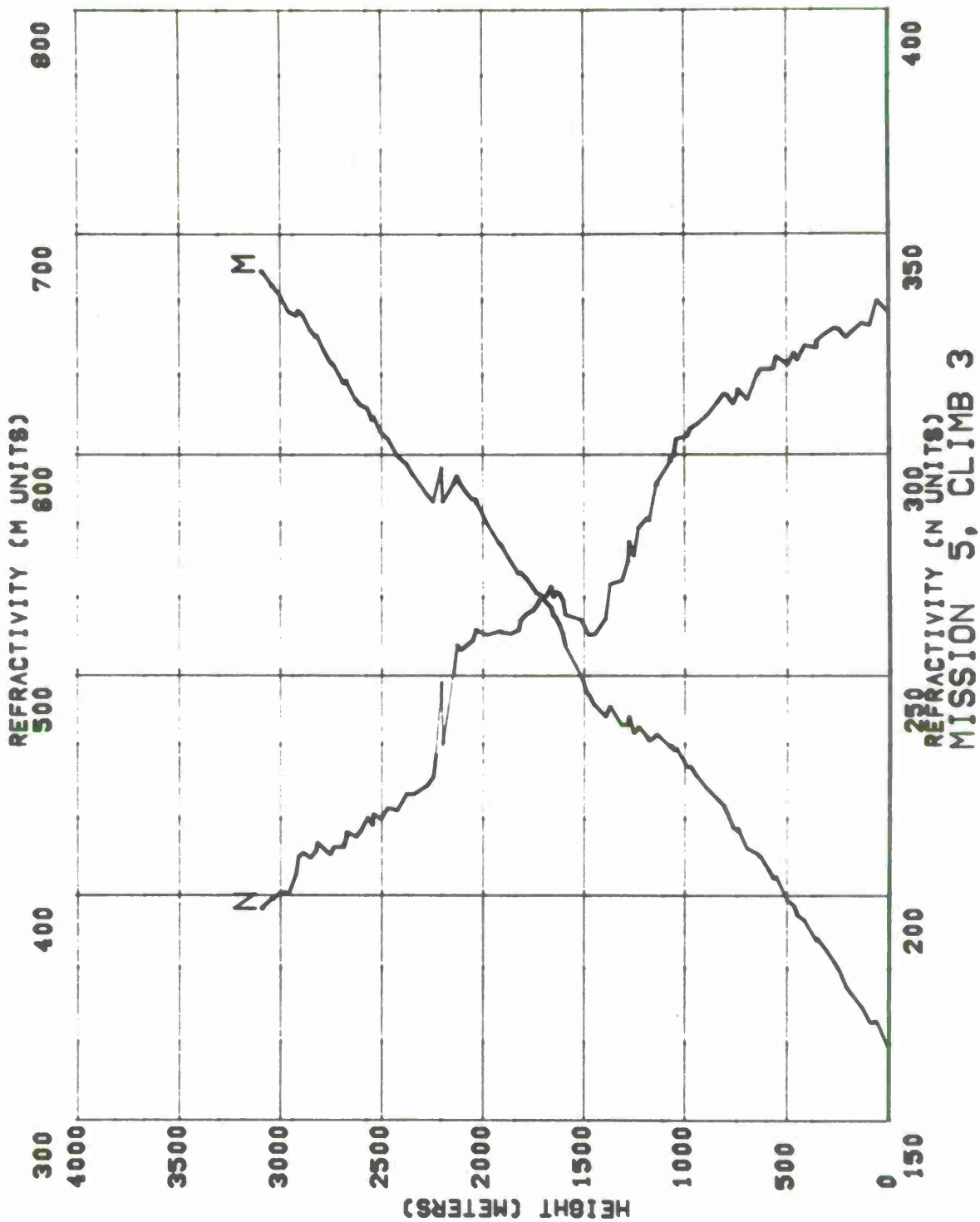
MISSION 5, CLIMB 2

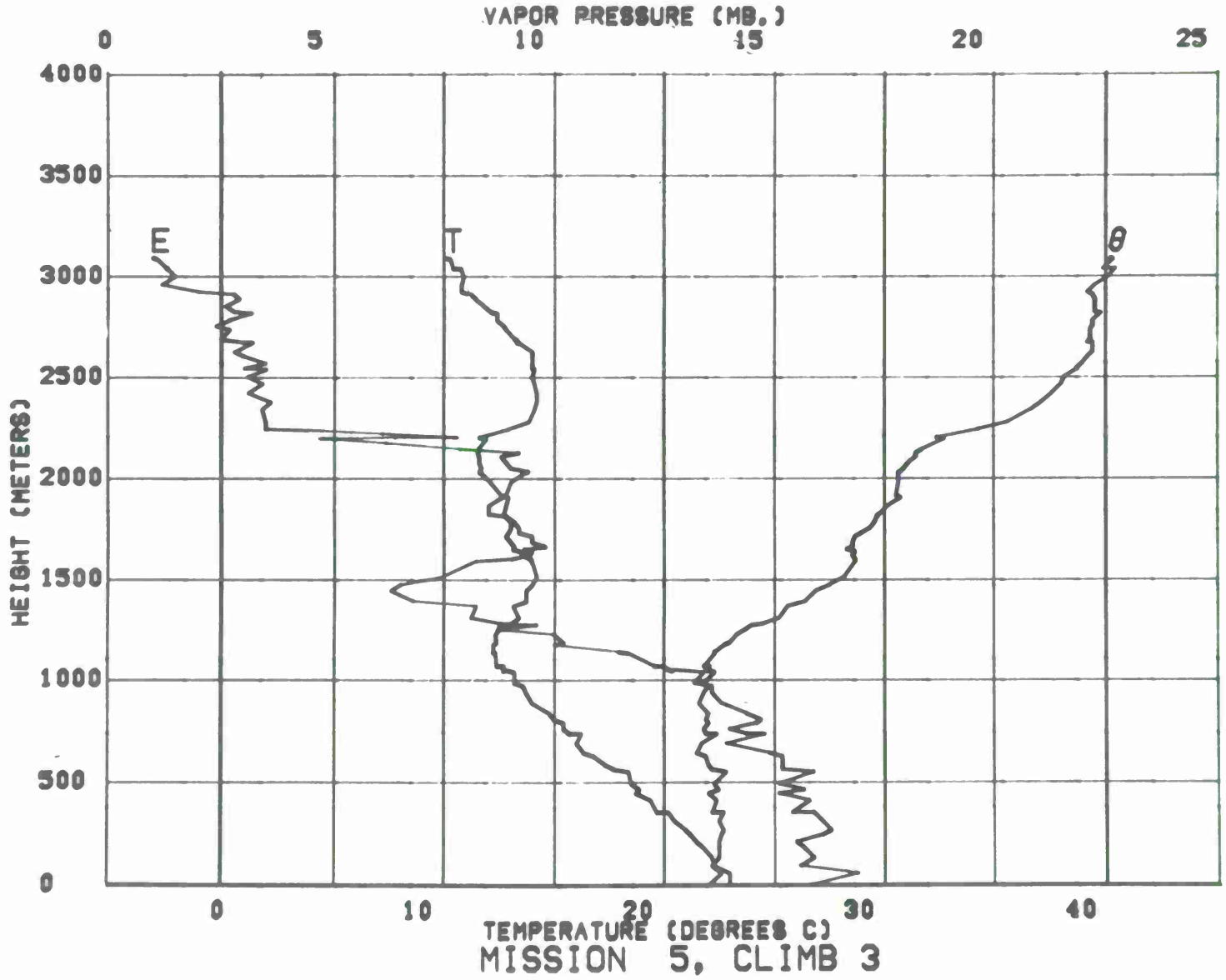

MISSION 5, CLIMB 2
VAPOR PRESSURE (MB.)
TEMPERATURE (DEGREES C)
HEIGHT (METERS)
0
5
10
15
20
25
0
10
20
30
40
4000
3500
3000
2500
2000
1500
1000
500
0
D
T



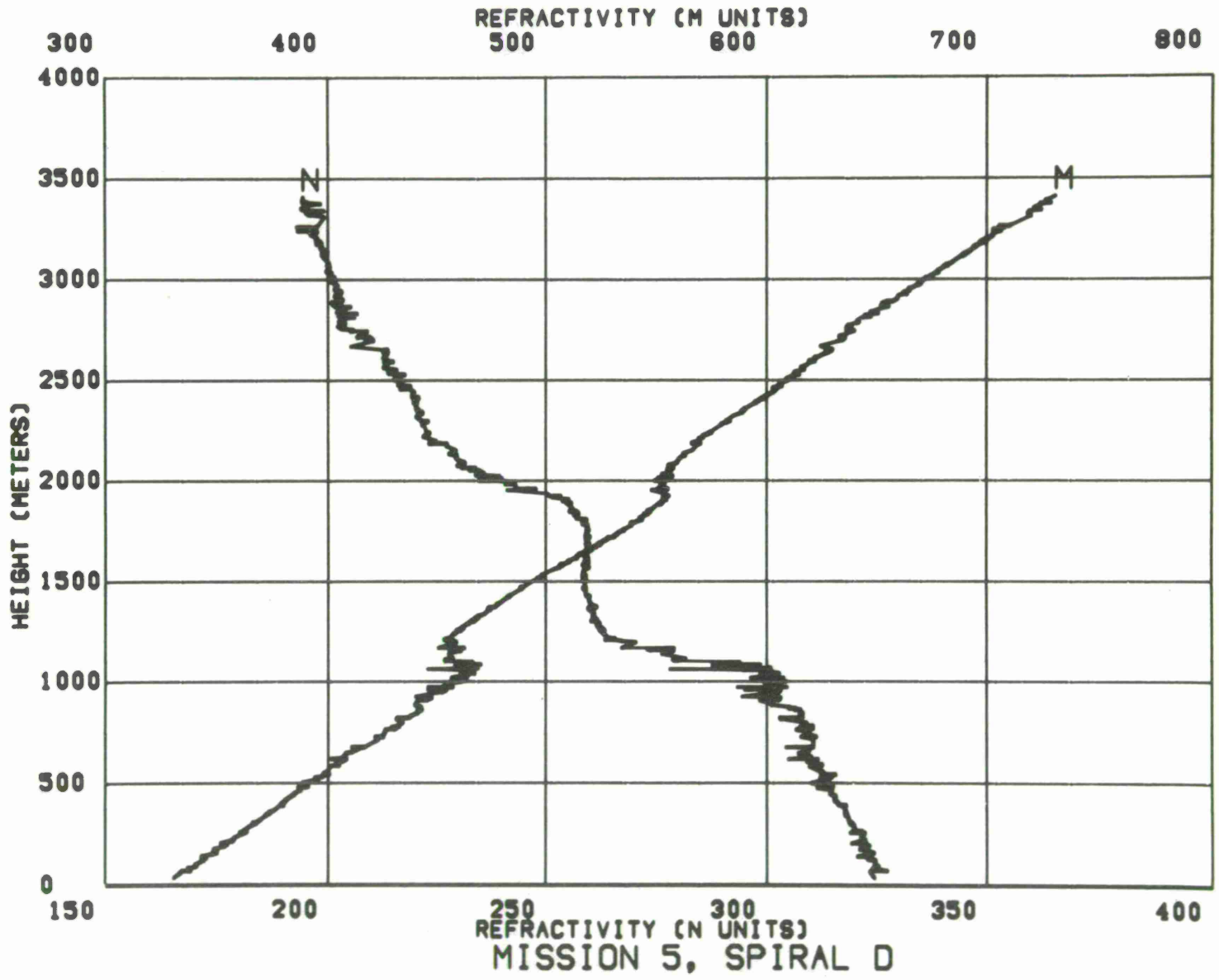
MISSION 5, SPRIAL C


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
T
θ
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 5, SPRIAL C

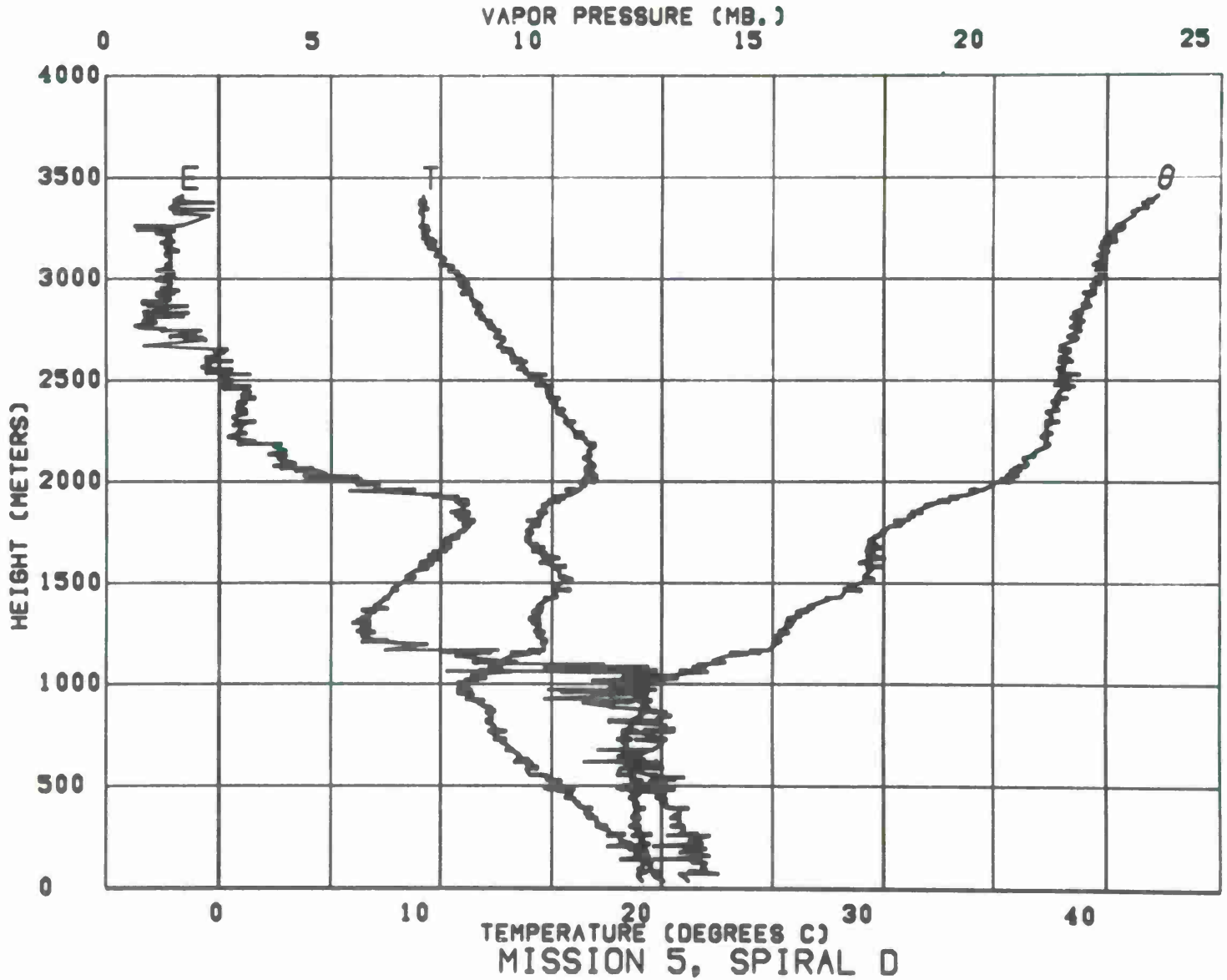

MISSION 5, CLIMB 3
REFRACTIVITY (M UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
M
N
300
400
500
600
700
800
150
200
250
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000



MISSION 5, CLIMB 3



MISSION 5, SPIRAL D



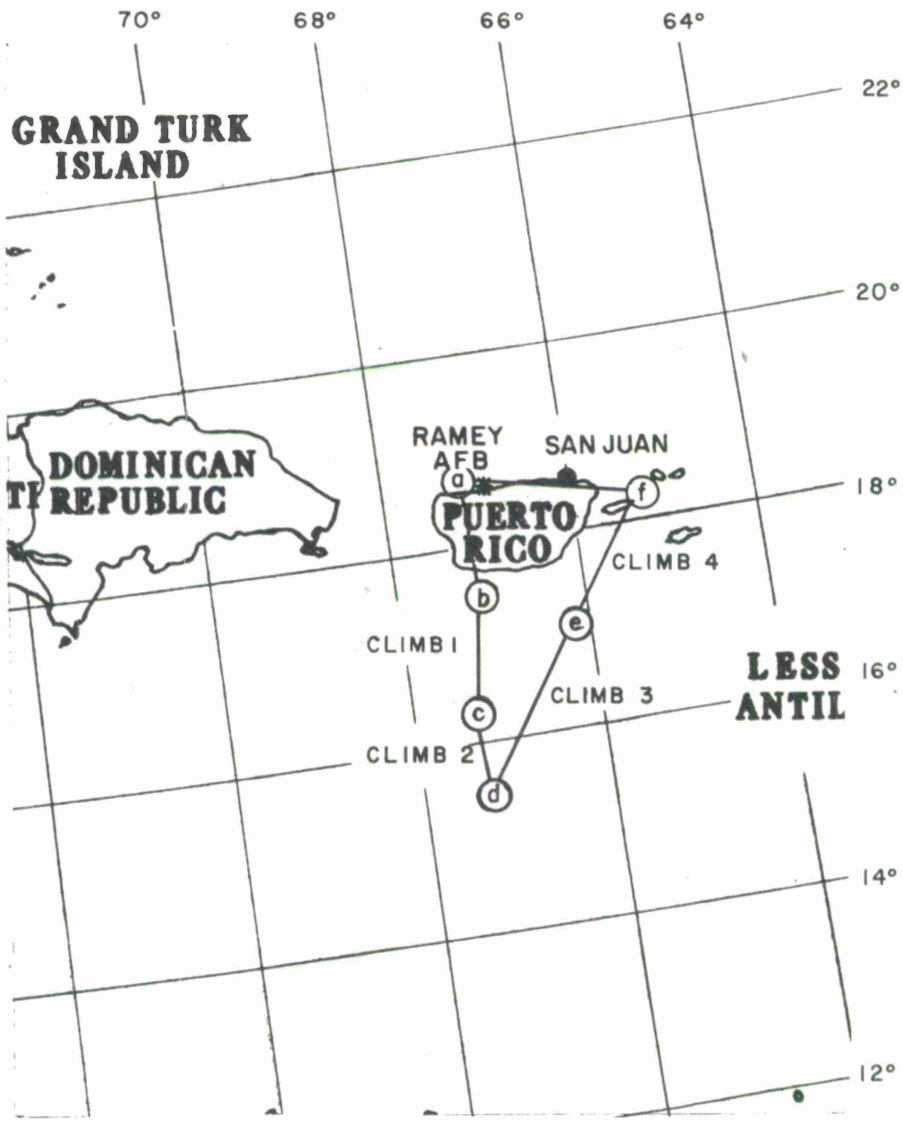
MISSION 5, SPIRAL D

MISSION NO. 6

Date: 14 March 1969

Data were obtained on six spirals and four ascents along Flight Path V, southward and eastward from Ramey AFB, Puerto Rico.

Spiral	Location	Spiral Start Time Z	Local
A	a. 18-36 N, 62-00 W	1629	1229
B	b. 17-30 N, 67-00 W	1706	1306
Climb 1	b-c	1726	1326
C	c. 16-17 N, 67-17 W	1810	1410
Climb 2	c-d	1828	1428
D	d. 15-37 N, 67-23 W	1848	1448
Climb 3	d-e	1905	1505
E	d. 17-03 N, 66-14 W	1945	1545
Climb 4	e-f	2003	1603
F	f. 18-34 N, 65-37 W	2033	1633

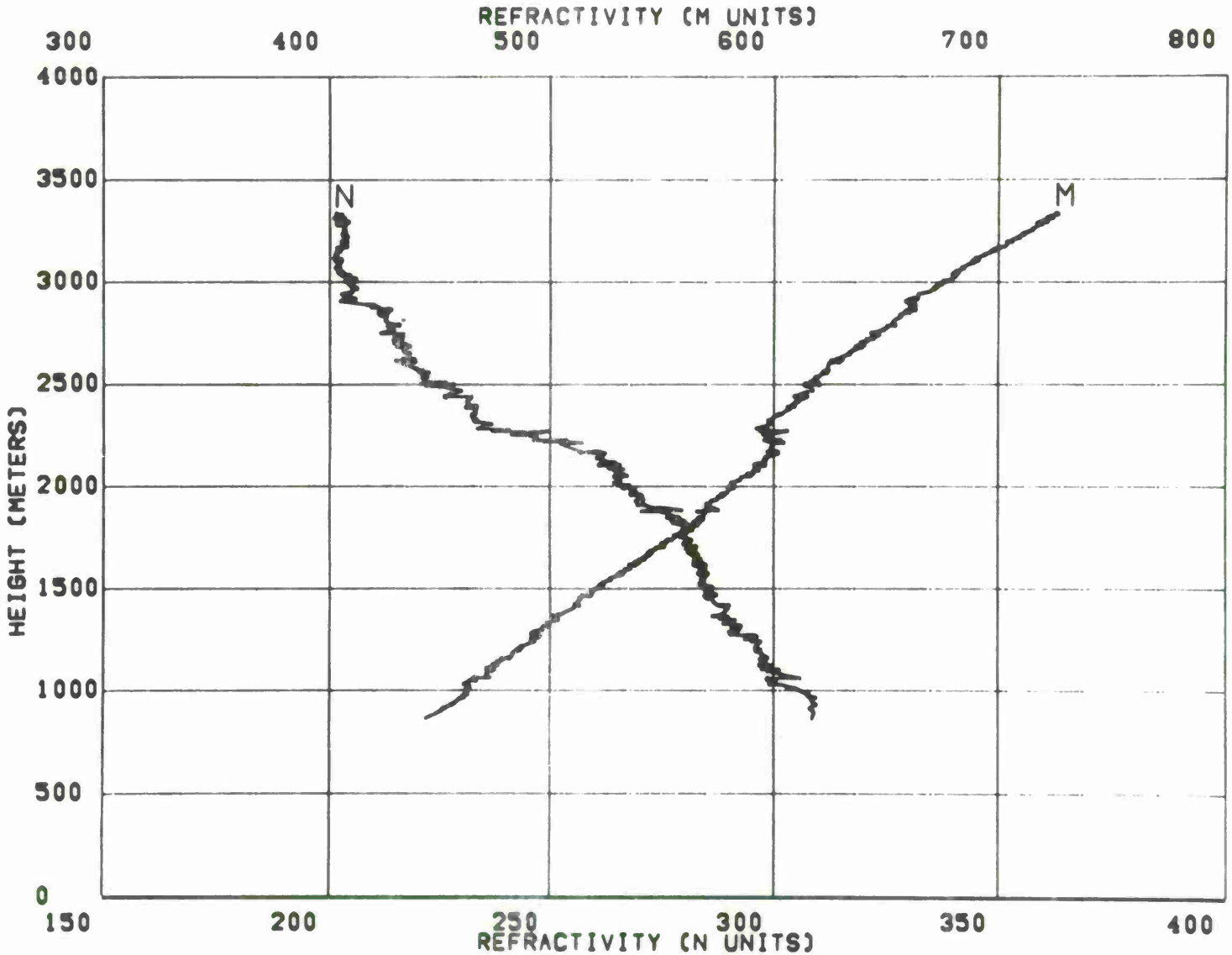


SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

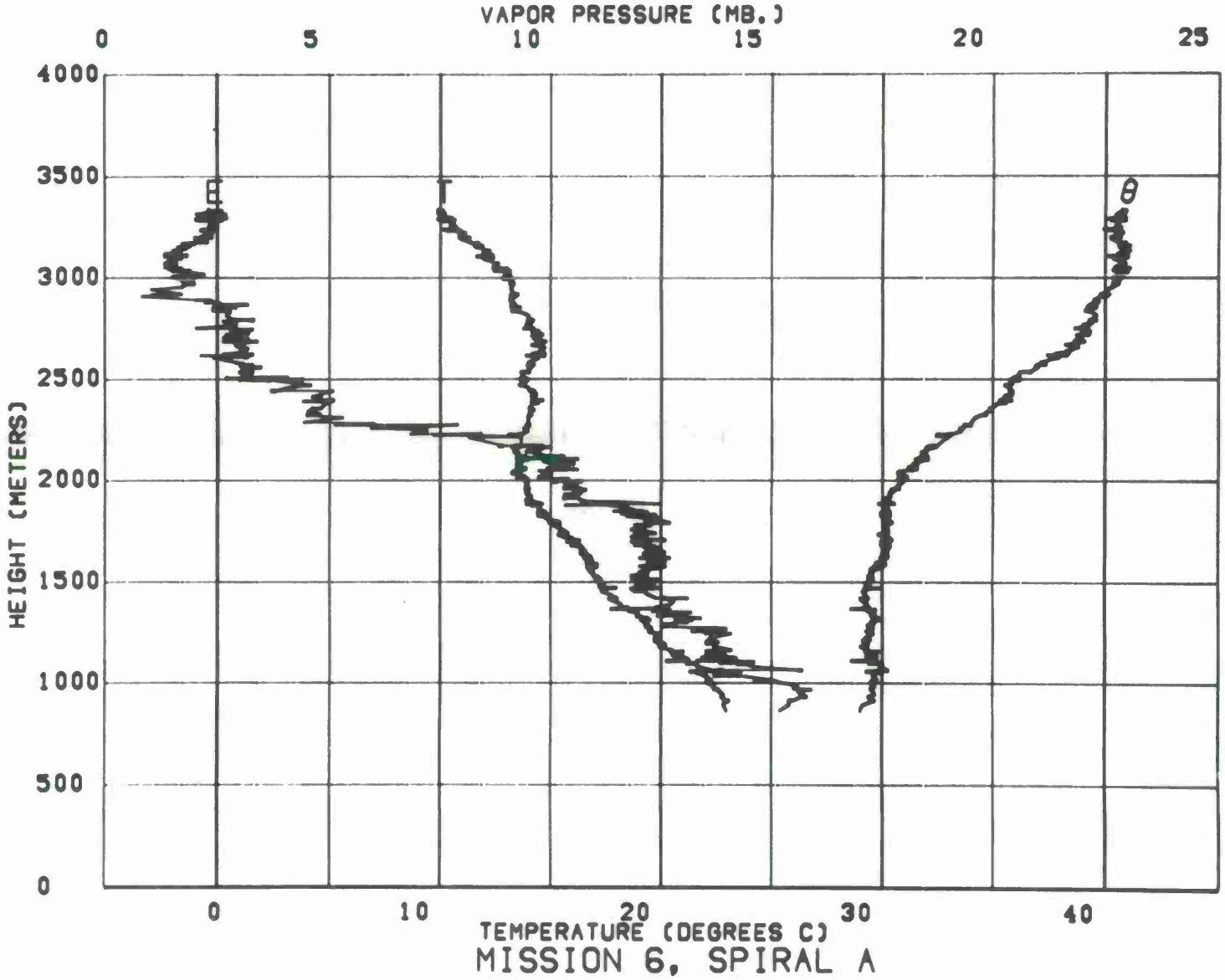
100 50 0 100 200 300
STATUTE MILES

100 50 0 100 200 300 400
KILOMETERS

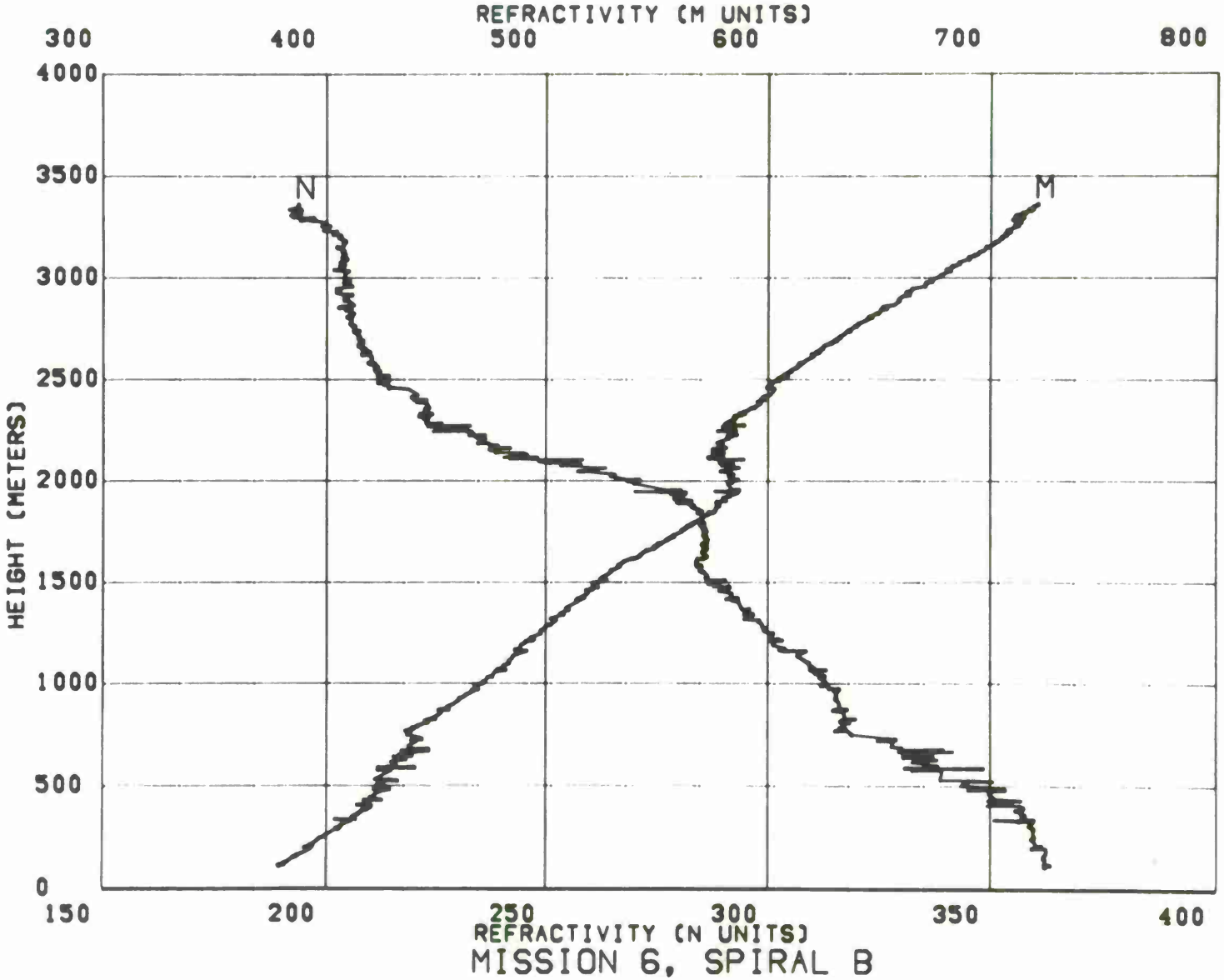
FLIGHT PATH V
MISSION 6 — 14 MARCH 1969



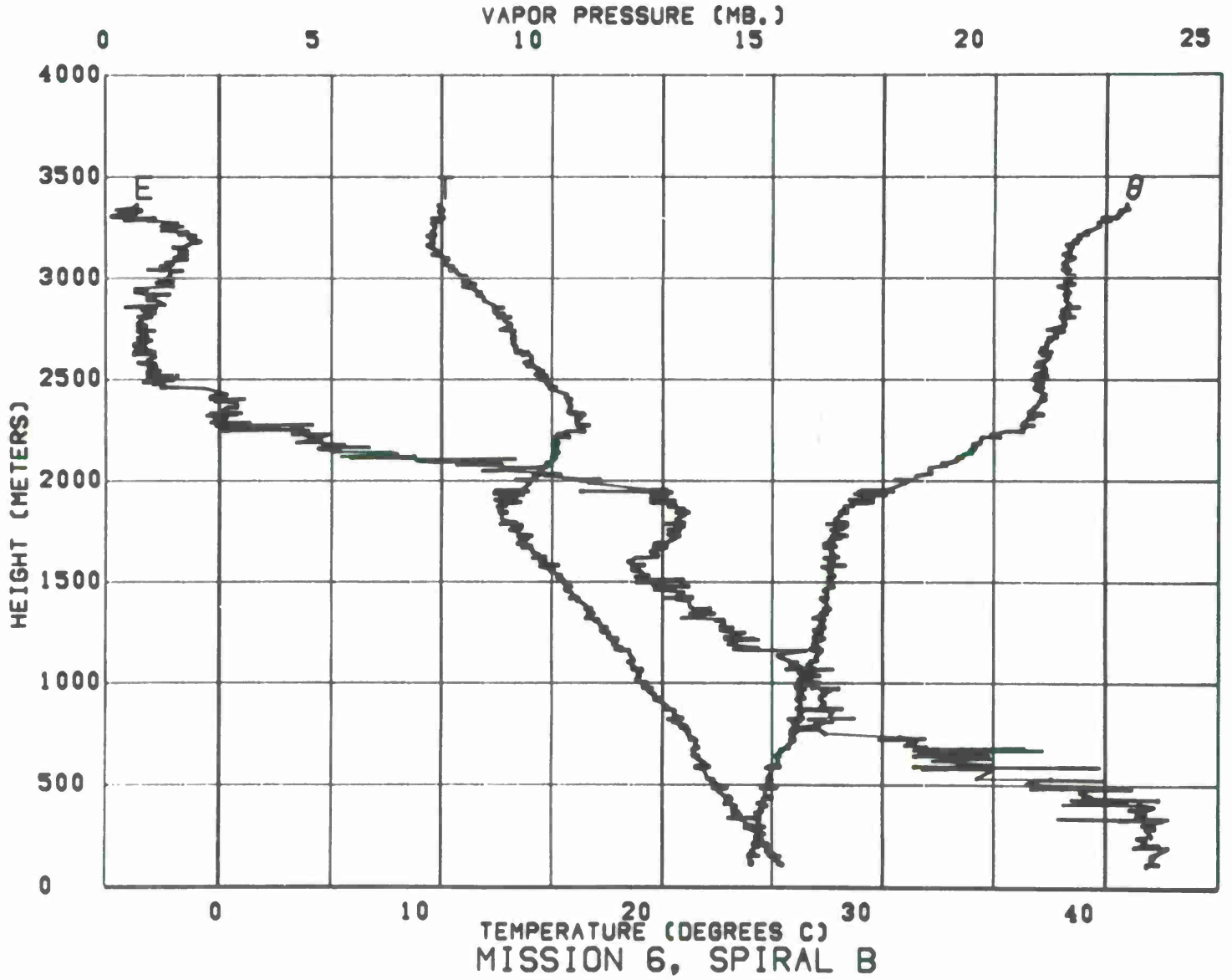
MISSION 6, SPIRAL A



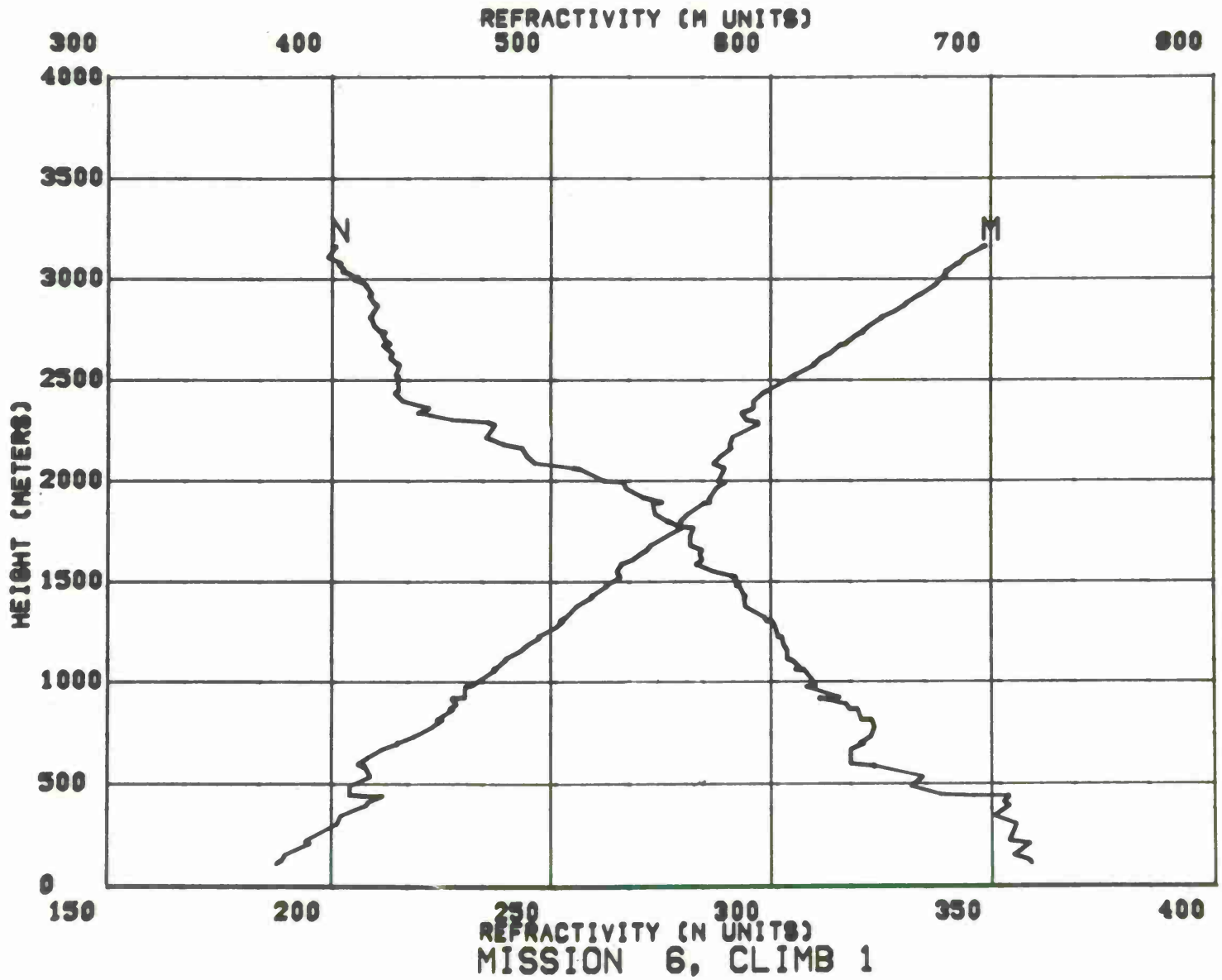
MISSION 6, SPIRAL A



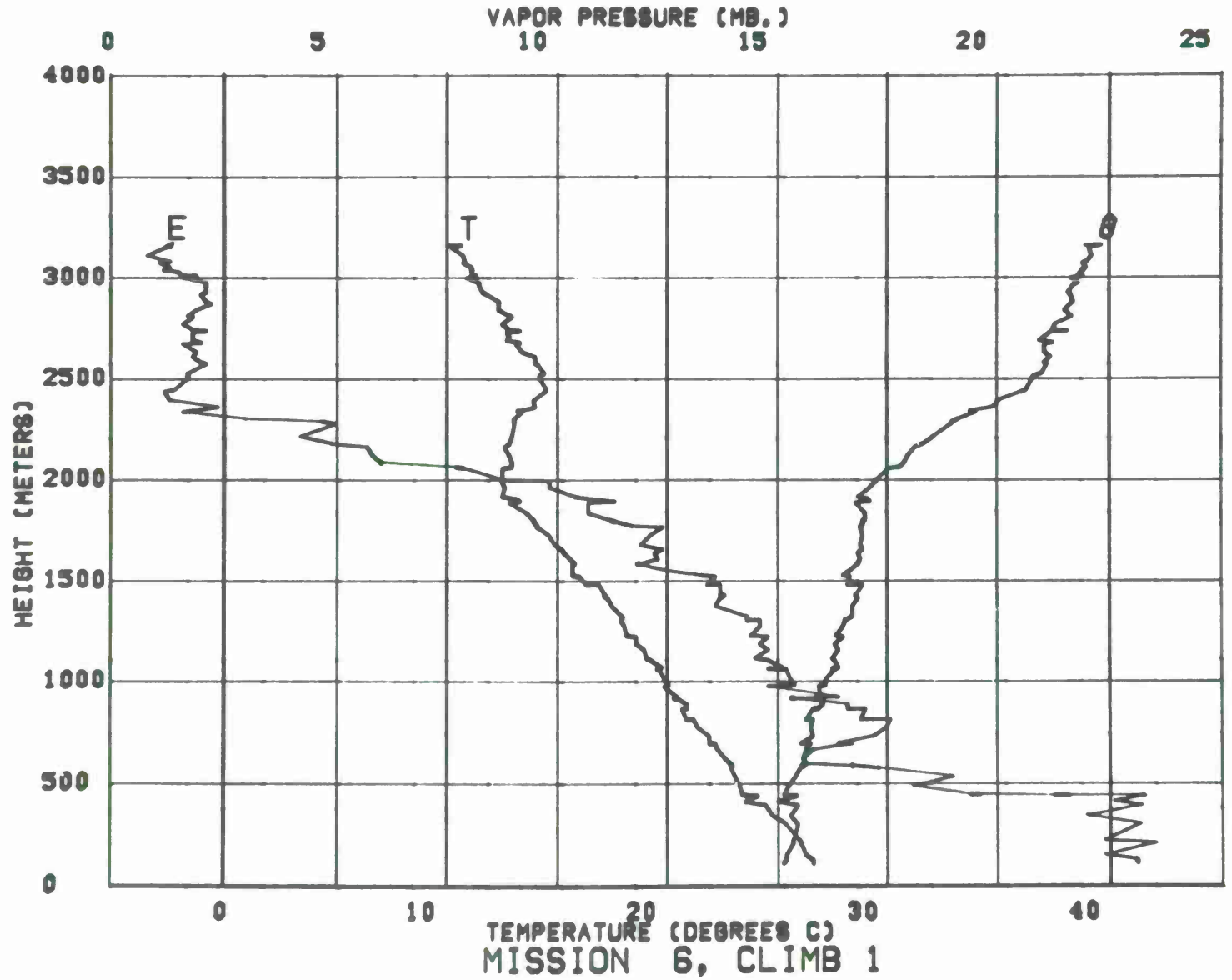
MISSION 6, SPIRAL B



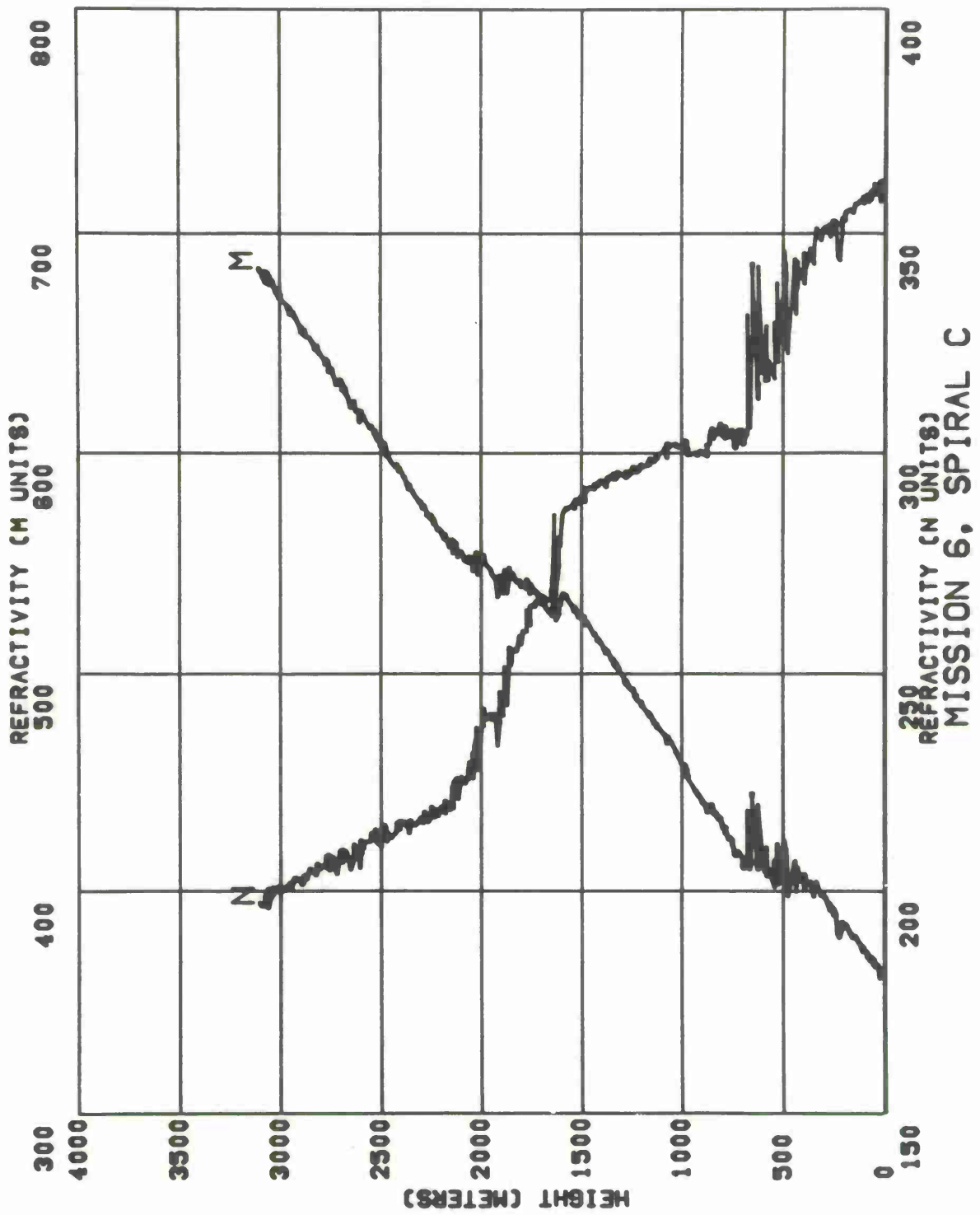
MISSION 6, SPIRAL B

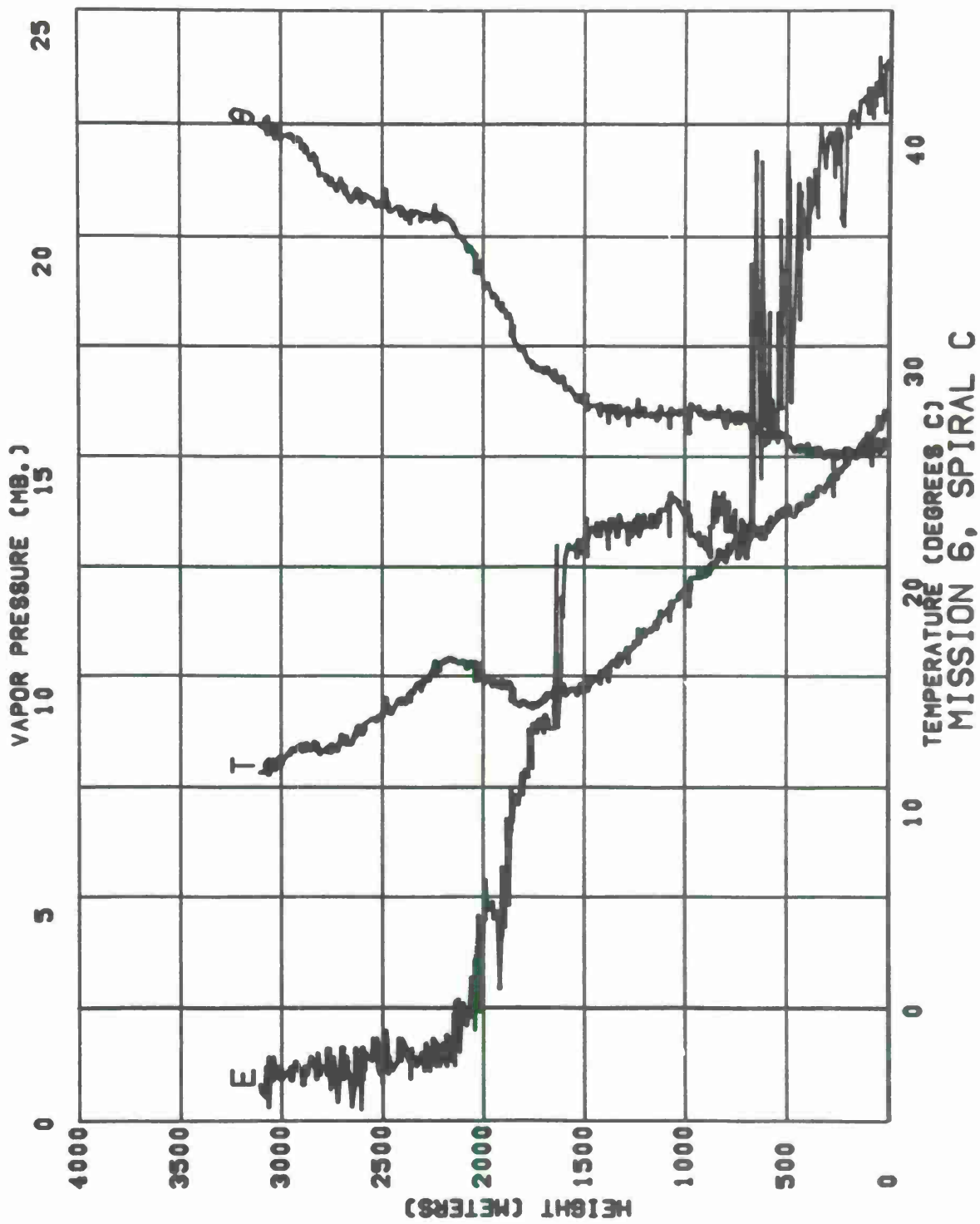


MISSION 6, CLIMB 1



MISSION 6, CLIMB 1


MISSION 6, SPIRAL C
REFRACTIVITY (M UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
M
N
300
400
500
600
700
800
150
200
250
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000


VAPOR PRESSURE (MB.)
0
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25
HEIGHT (METERS)
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TEMPERATURE (DEGREES C)
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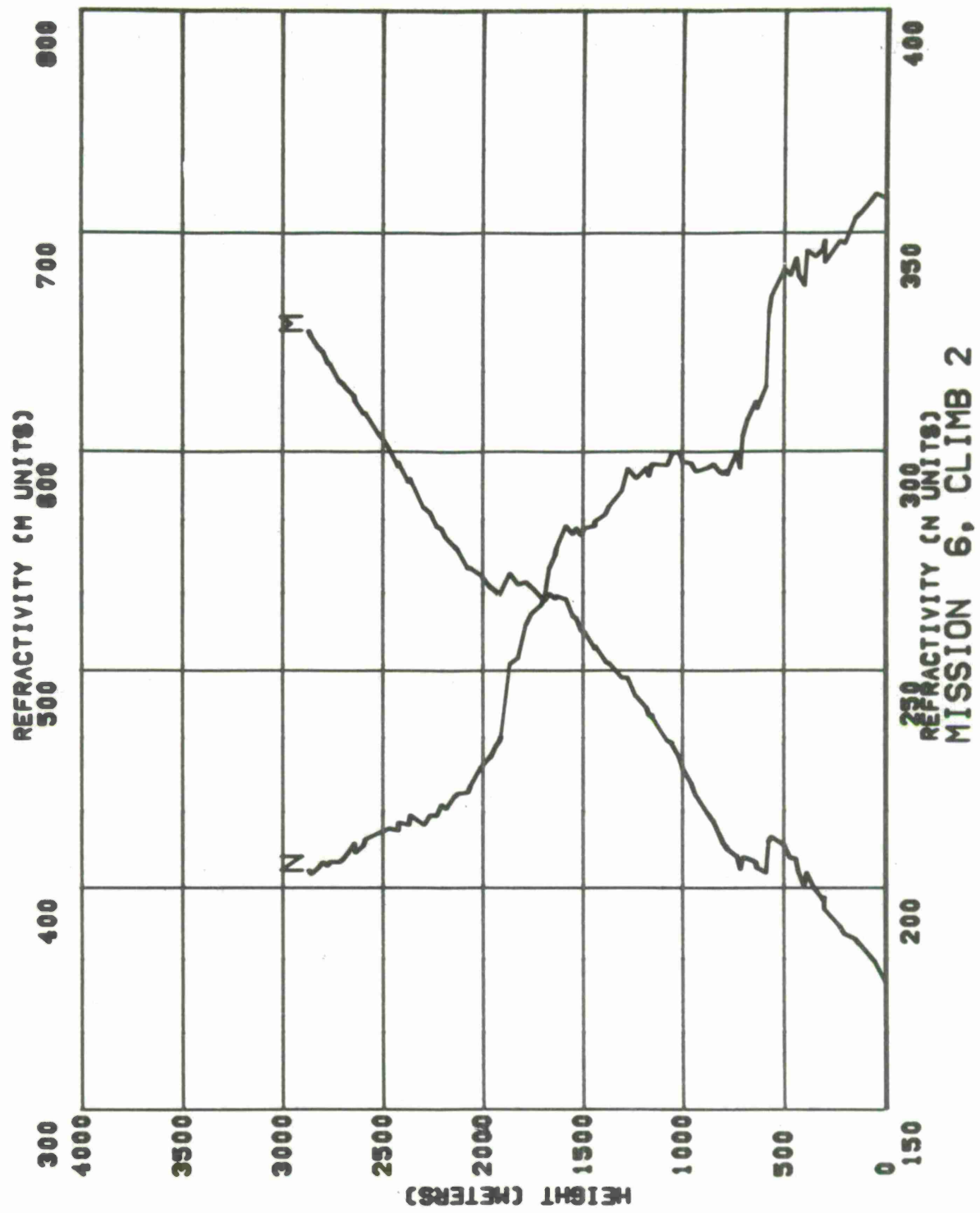
MISSION 6, SPIRAL C


MISSION 6, CLIMB 2
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
REFRACTIVITY (N UNITS)
M
N
300
400
500
600
700
800
150
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300
350
400
0
500
1000
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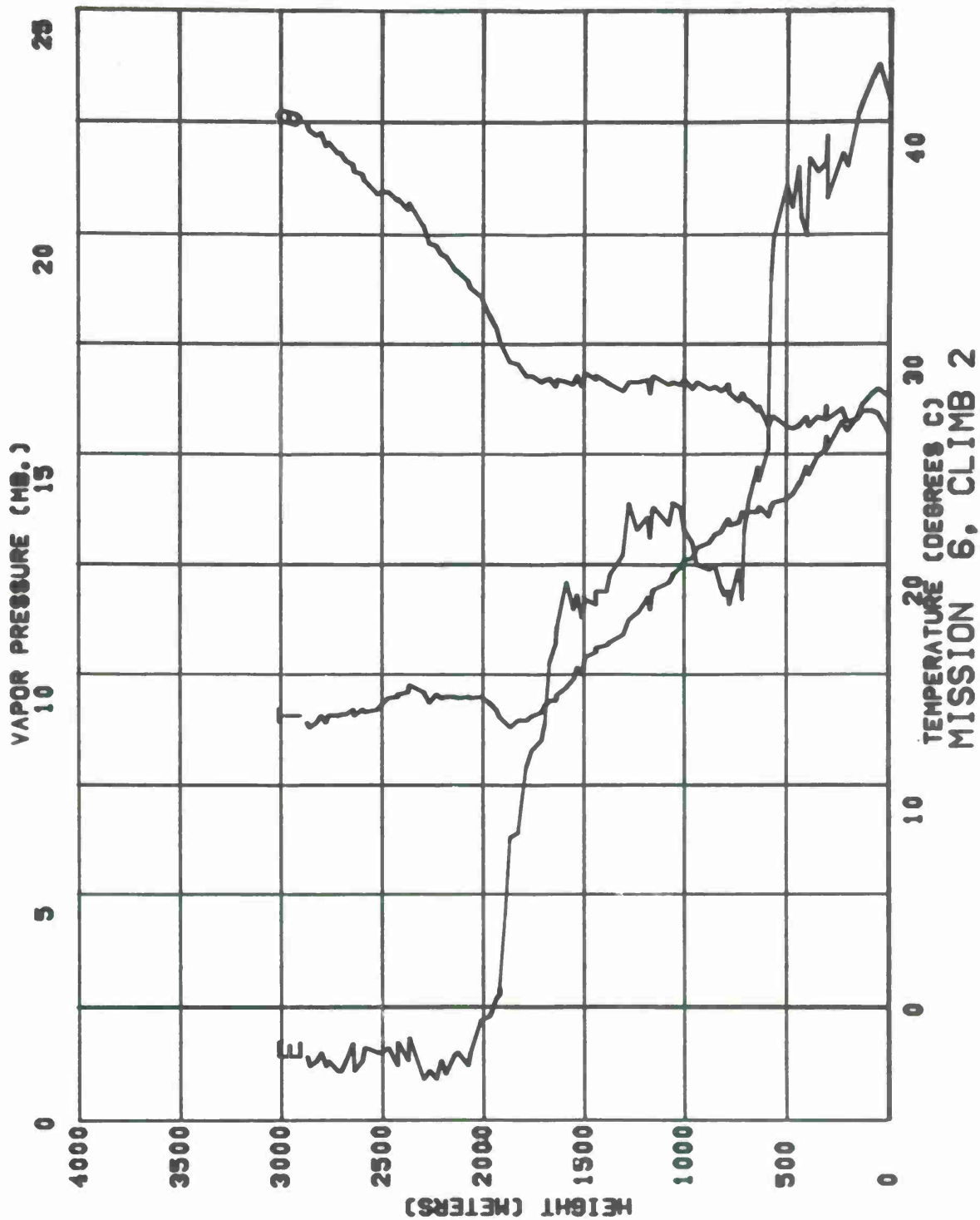
2500
3000
3500
4000


MISSION 6, CLIMB 2
VAPOR PRESSURE (MB.)
TEMPERATURE (DEGREES C)
HEIGHT (METERS)
0
5
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15
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0
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4000
3500
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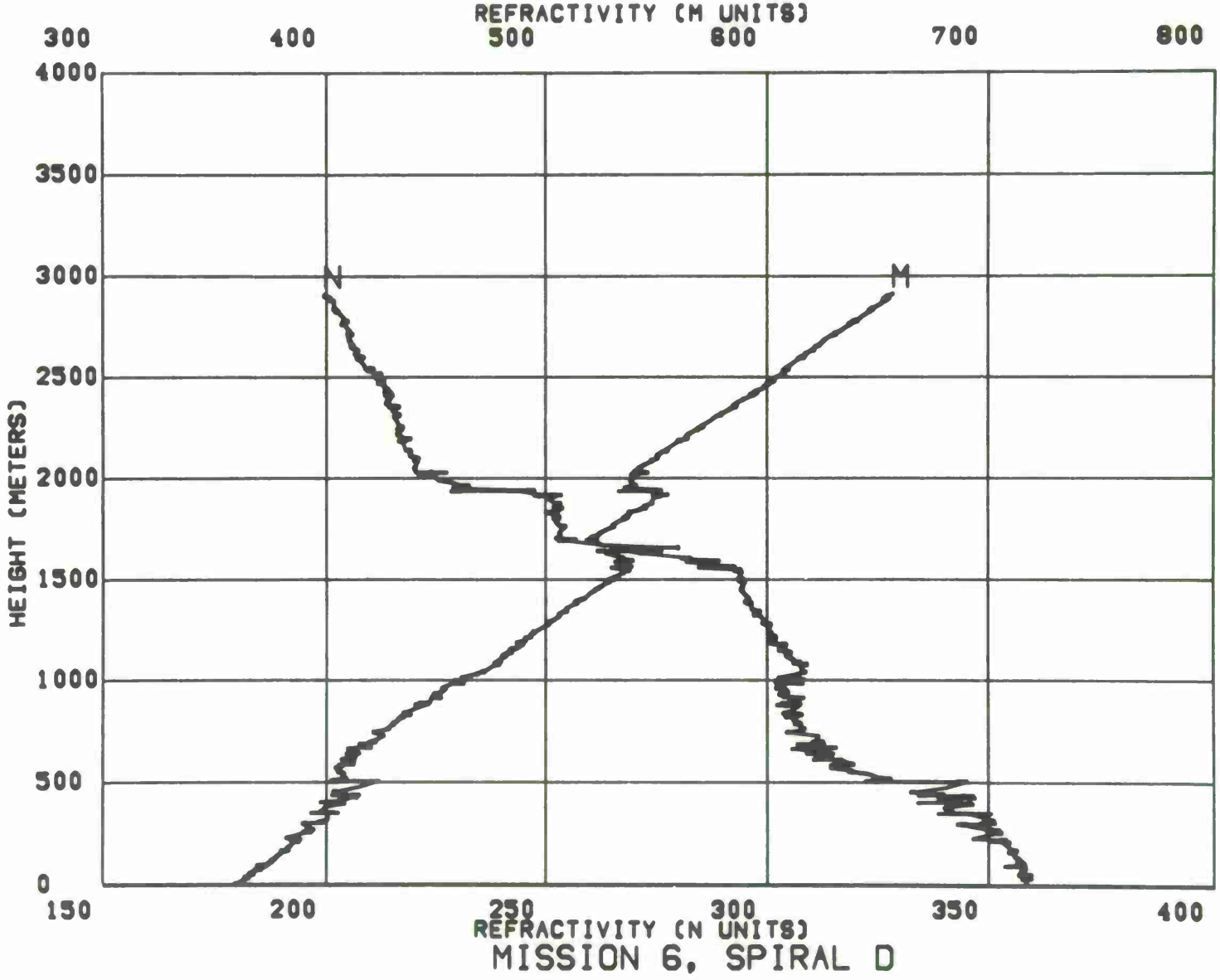
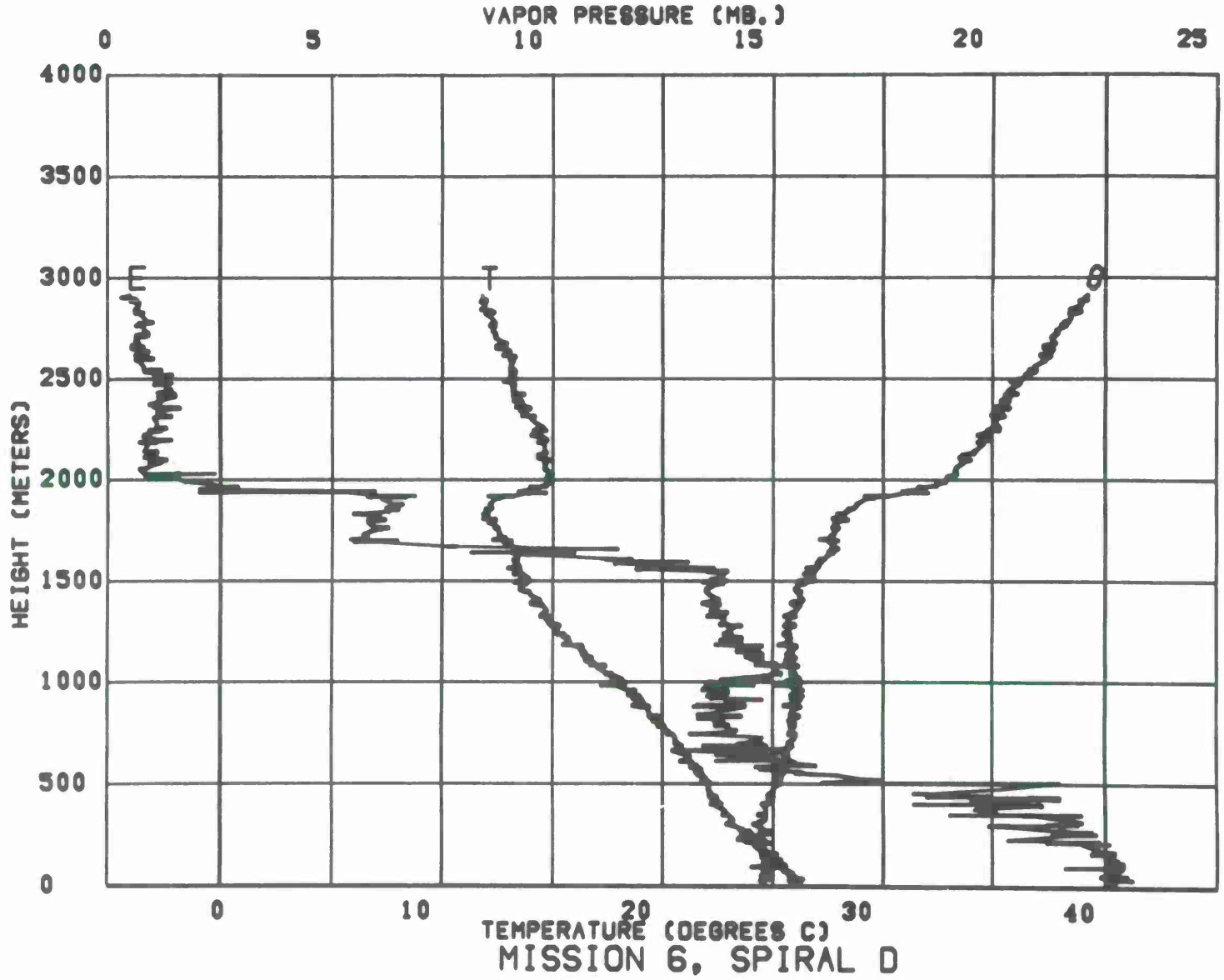
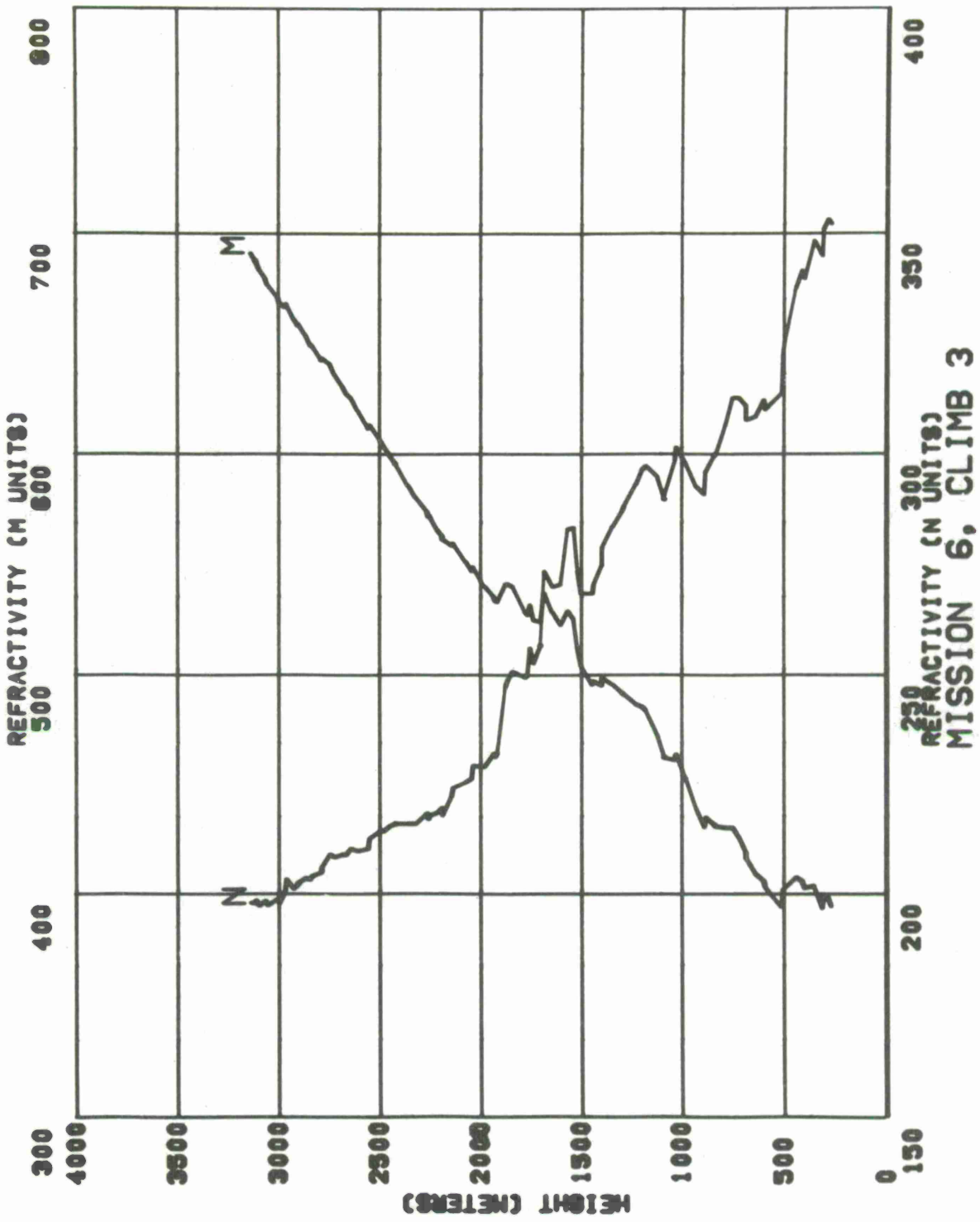


MISSION 6, SPIRAL D



MISSION 6, SPIRAL D


MISSION 6, CLIMB 3
REFRACTIVITY (M UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
M
N
300
400
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800
150
200
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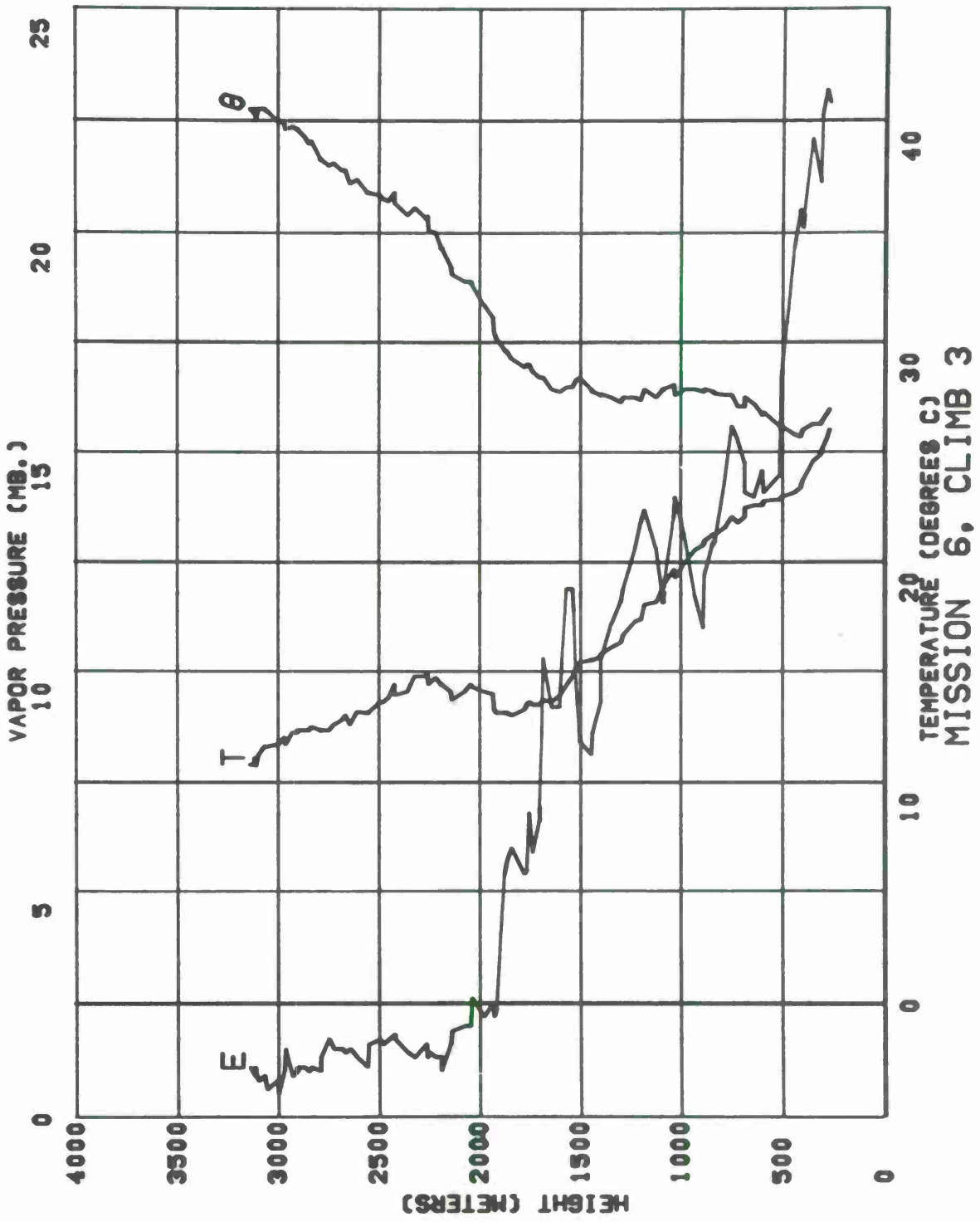
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000


MISSION 6, CLIMB 3
VAPOR PRESSURE (MB.)
TEMPERATURE (DEGREES C)
HEIGHT (METERS)
θ
T
E
0
5
10
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-10
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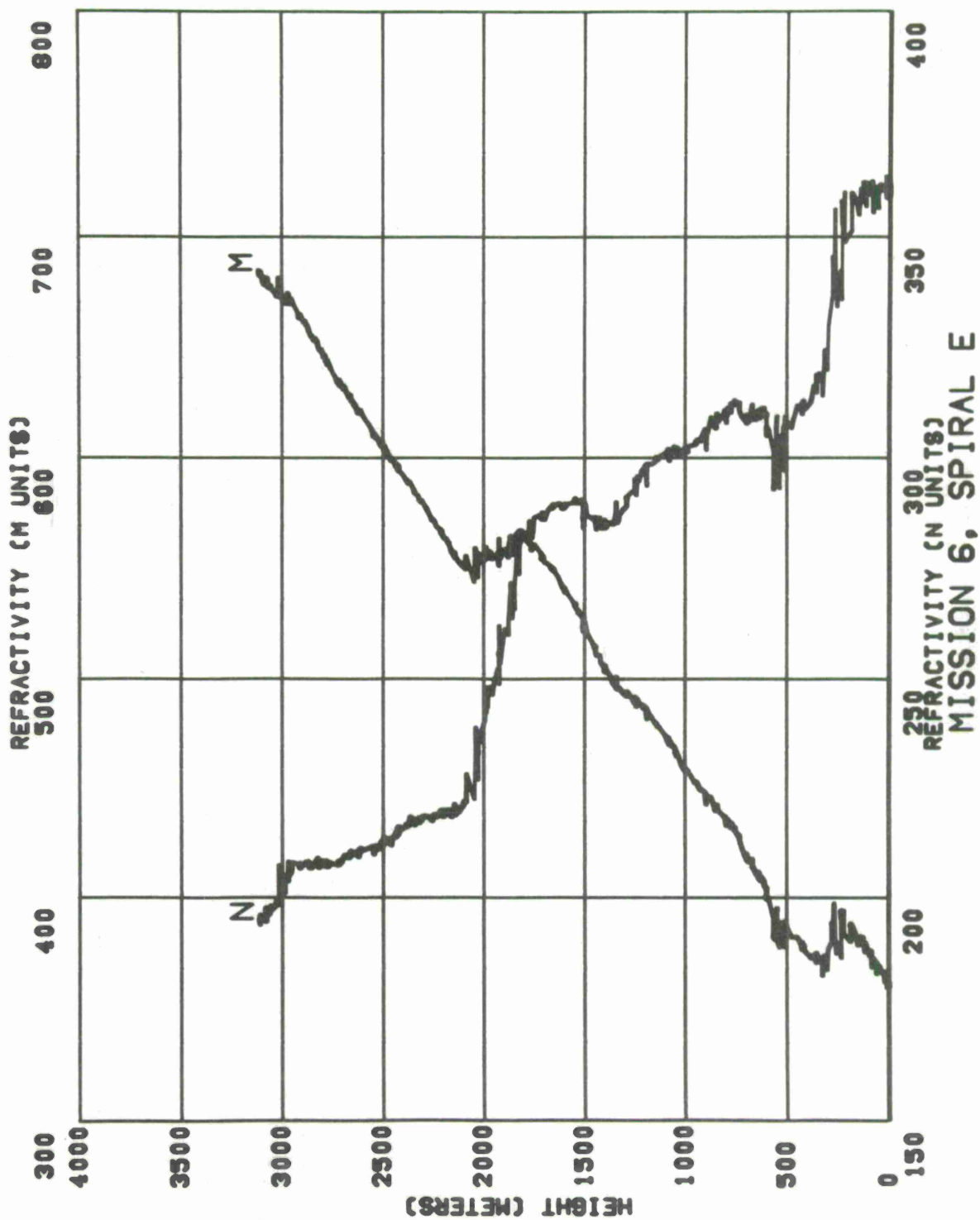
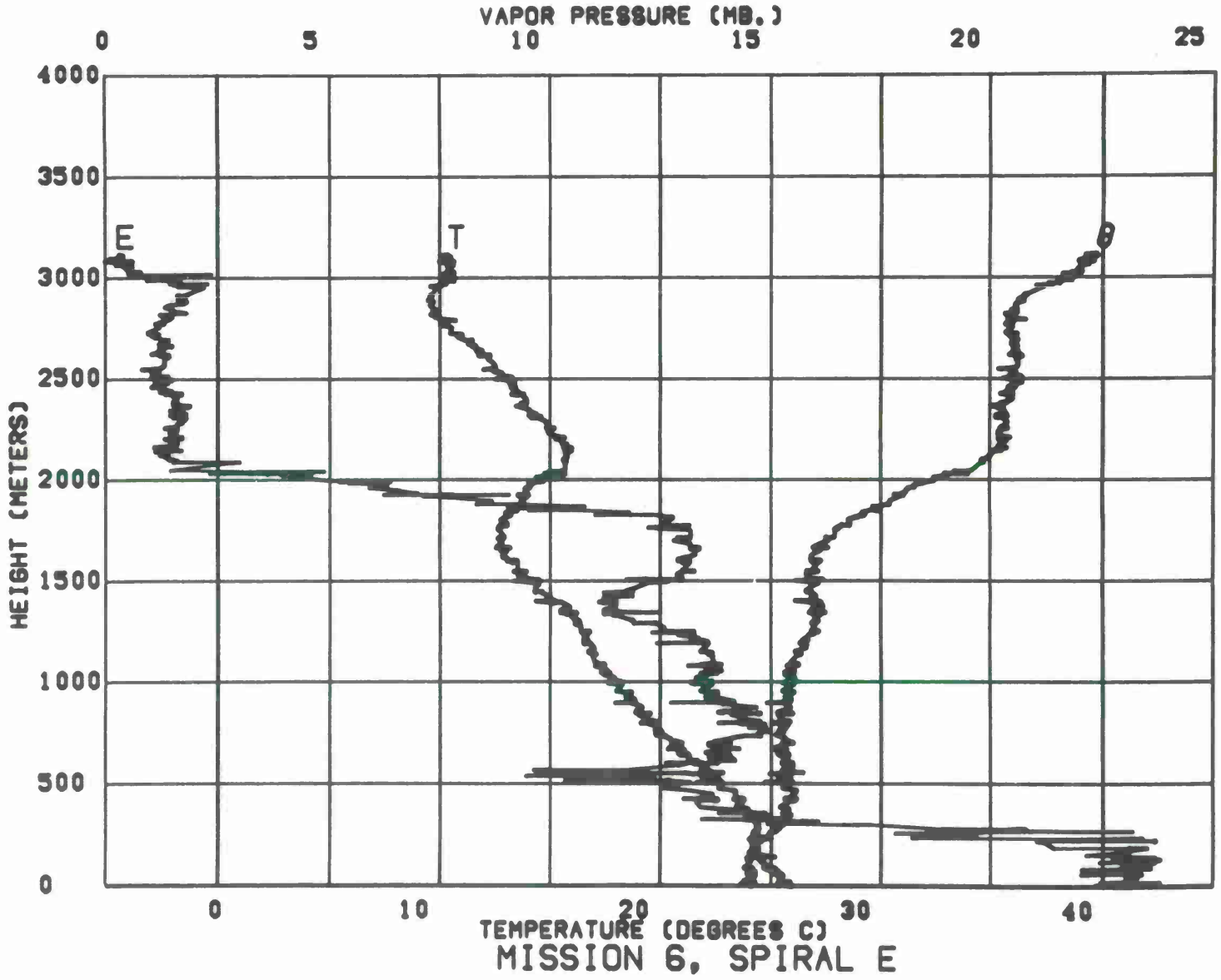
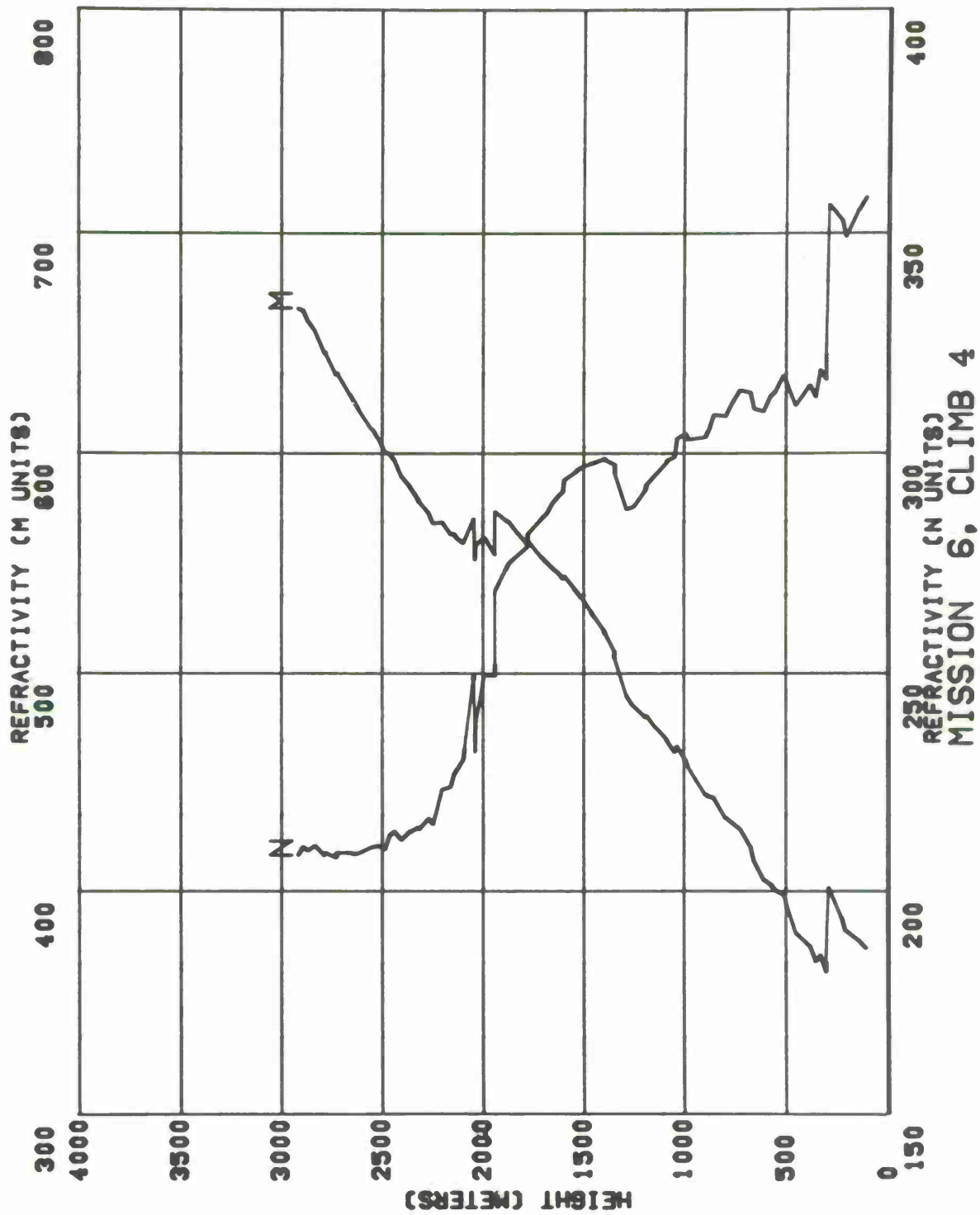
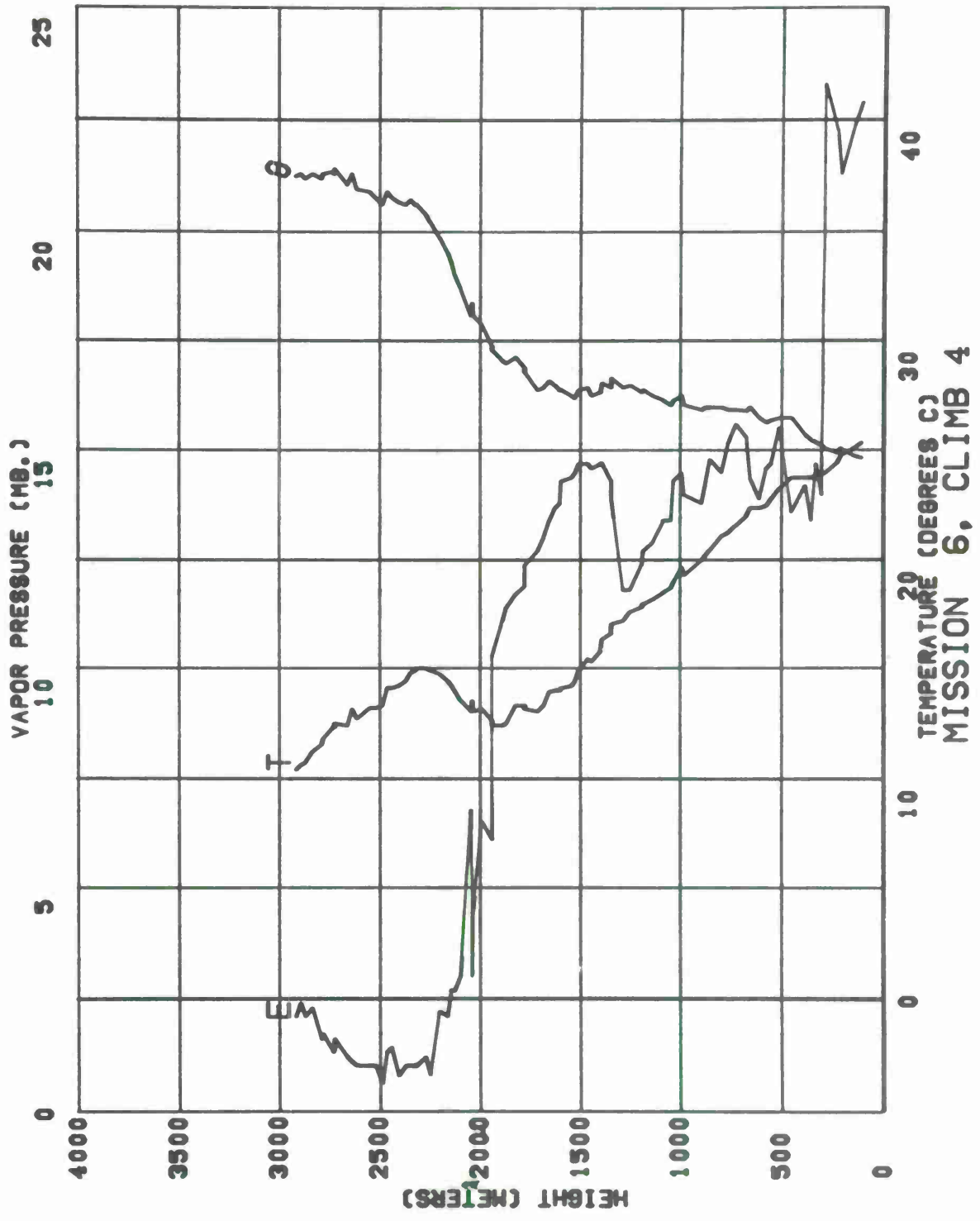
4000
3500
3000
2500
2000
1500
1000
500
0


MISSION 6, SPIRAL E
REFRACTIVITY (N UNITS)
REFRACTIVITY (M UNITS)
HEIGHT (METERS)
M
N
300
400
500
600
700
800
150
200
250
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000



MISSION 6, SPIRAL E


REFRACTIVITY (M UNITS)
800
700
600
500
400
300
REFRACTIVITY (N UNITS)
400
350
300
250
200
150
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
M
N
MISSION 6, CLIMB 4


MISSION 6, CLIMB 4
VAPOR PRESSURE (MB.)
TEMPERATURE (DEGREES C)
HEIGHT (METERS)
0
5
10
15
20
25
0
10
20
30
40
4000
3500
3000
2500
2000
1500
1000
500
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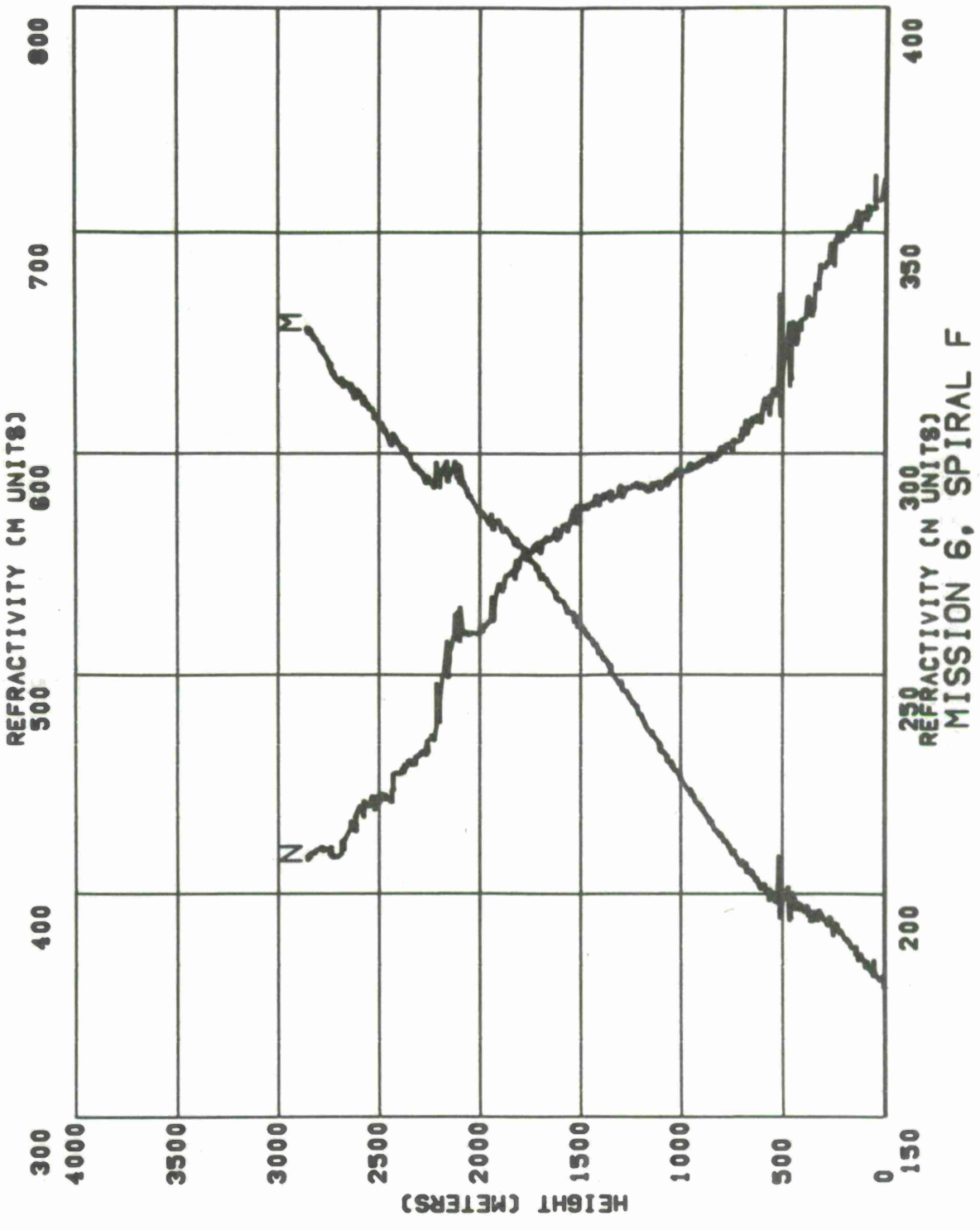
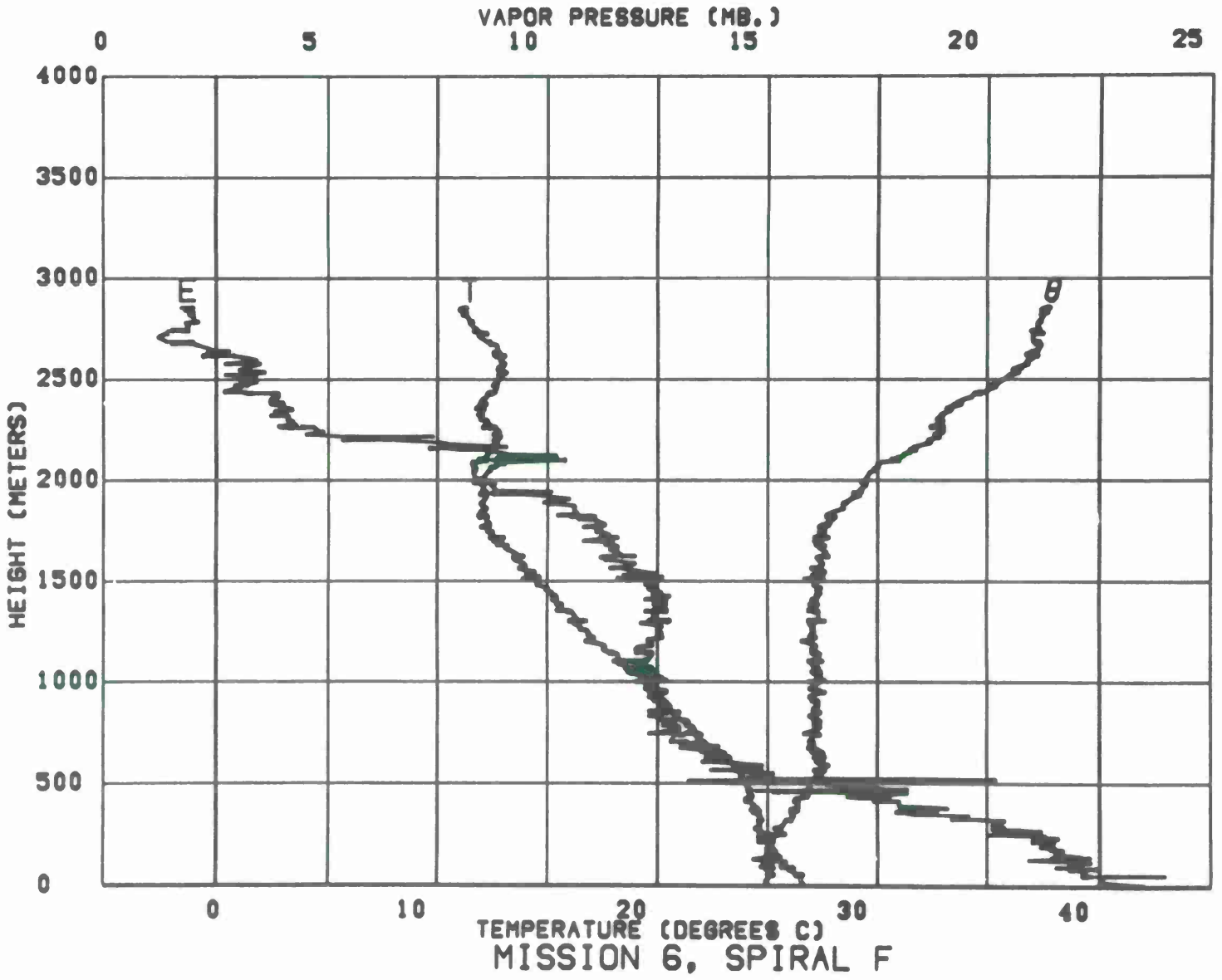
D
T
W


MISSION 6, SPIRAL F
REFRACTIVITY (M UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
M
N
300
400
500
600
700
800
250
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000
150
200



MISSION 6, SPIRAL F

MISSION NO. 7

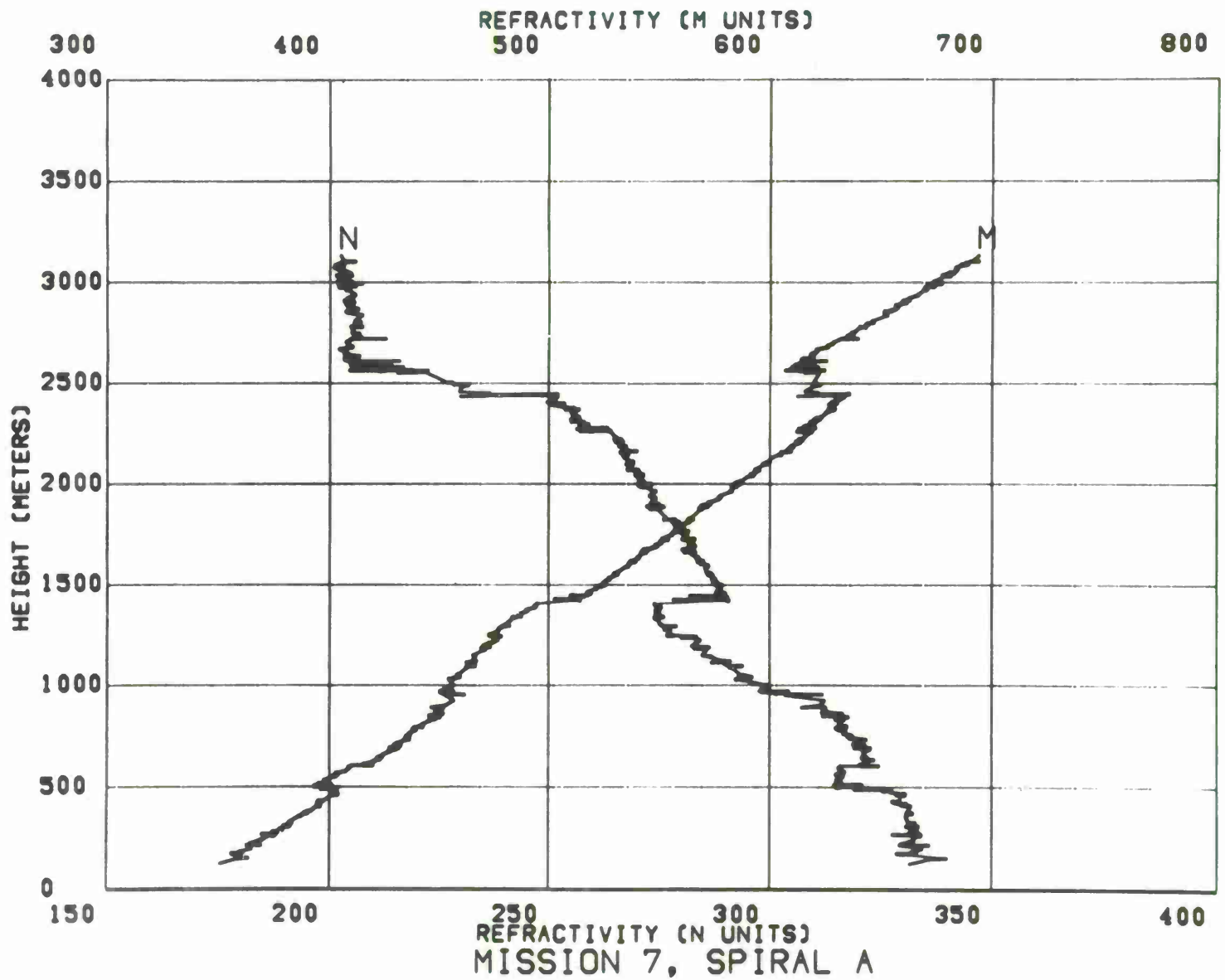
Date: 17 March 1969

Data were obtained on six spirals and four ascents along Flight Path VI, from Ramey AFB, Puerto Rico, to Grand Turk Island.

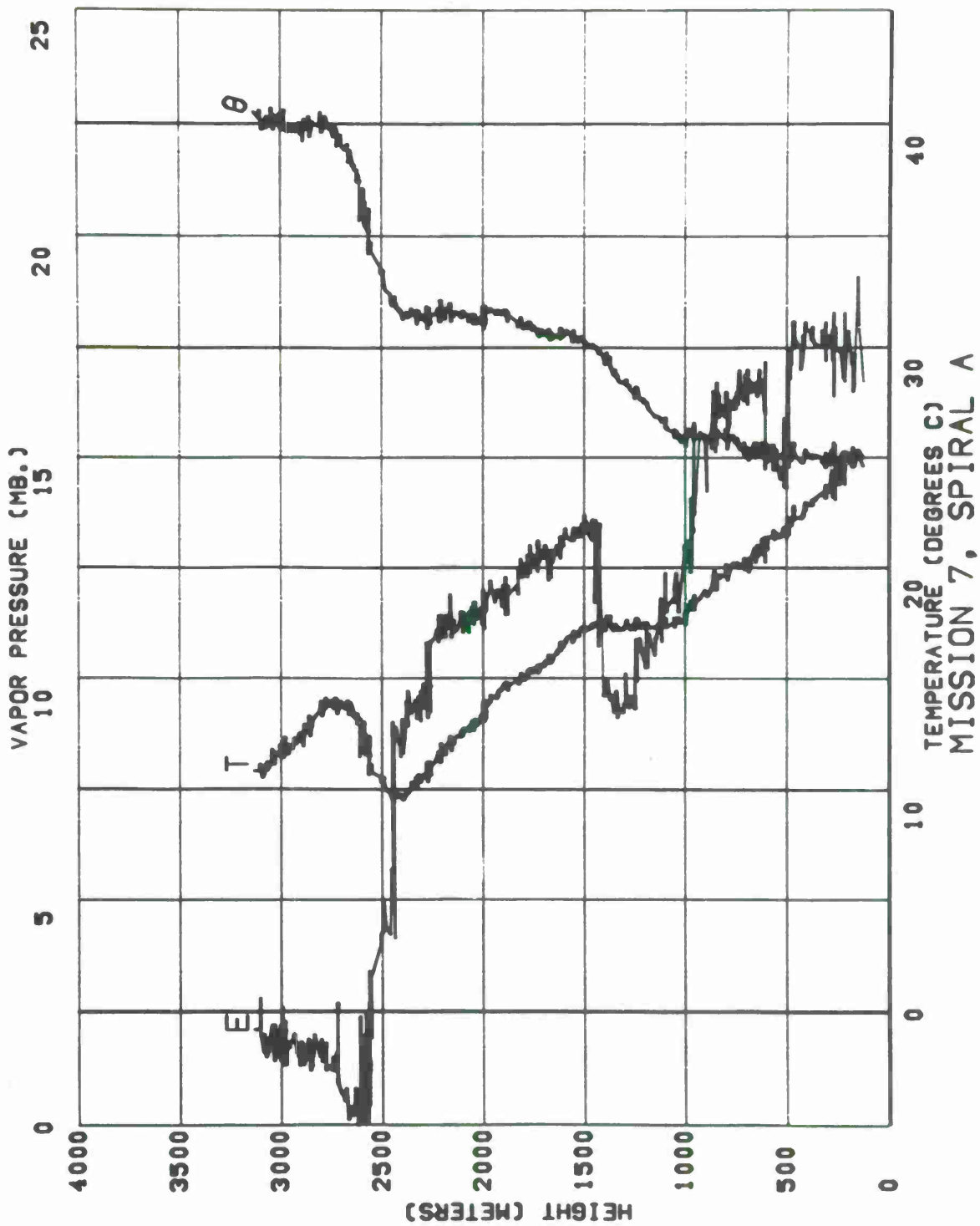
Spiral	Location	Spiral Start Time Z	Local
A	a. 18-32 N, 67-07 W	1702	1302
B	b. 19-10 N, 68-01 W	1744	1344
Climb 1	b-c	1800	1400
C	c. 19-53 N, 69-00 W	1828	1428
Climb 2	c-d	1848	1448
D	d. 20-36 N, 70-00 W	1915	1515
Climb 3	d-e	1932	1532
E	e. 20-34 N, 71-10 W	1955	1555
Climb 4	e-f	2013	1613
F	f. Grand Turk	2033	1633

FLIGHT PATH VI

MISSION 7 — 17 MARCH 1969



MISSION 7, SPIRAL A


MISSION 7, SPIRAL A
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
VAPOR PRESSURE (MB.)
0
5
10
15
20
25
TEMPERATURE (DEGREES C)
0
10
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30
40
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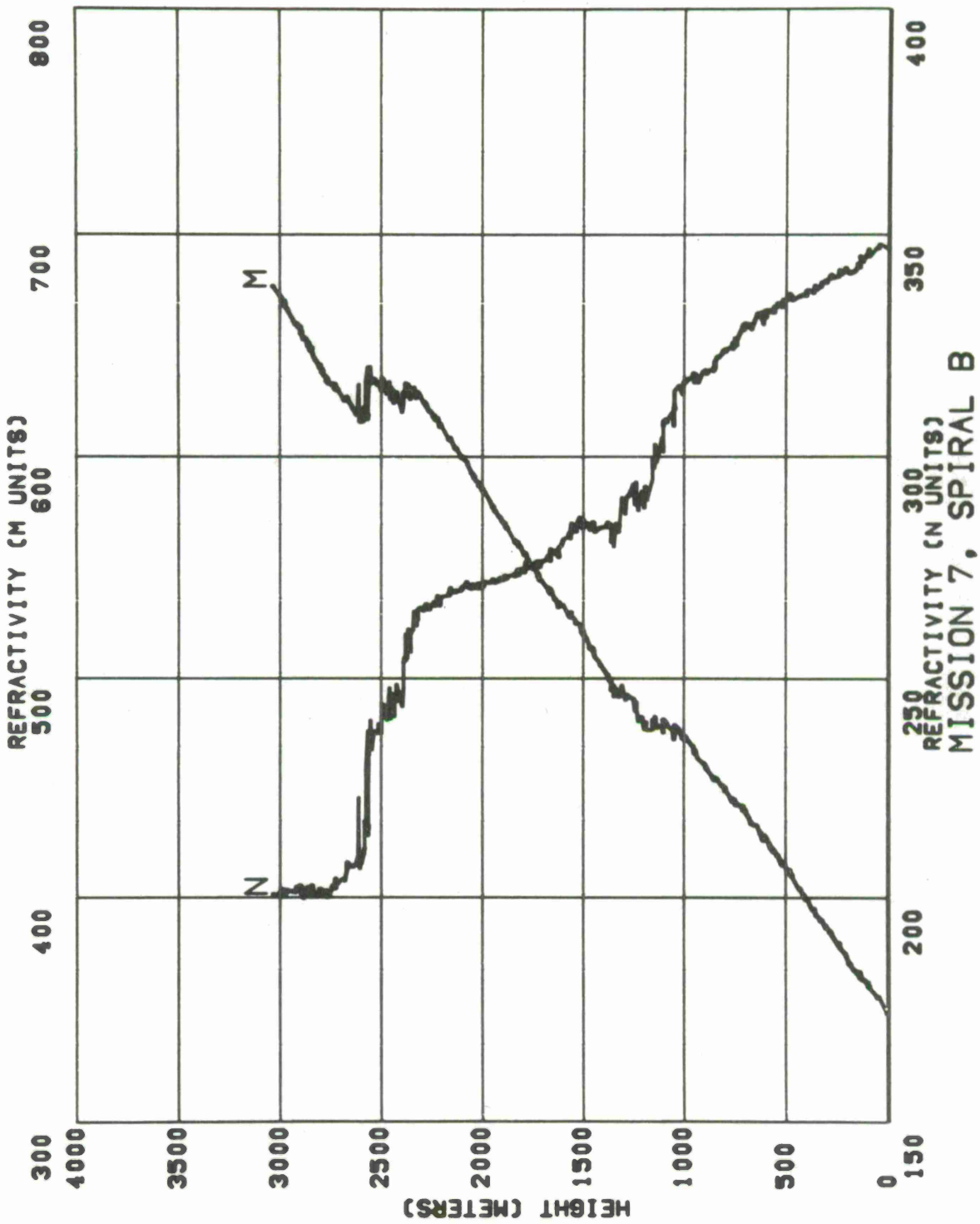
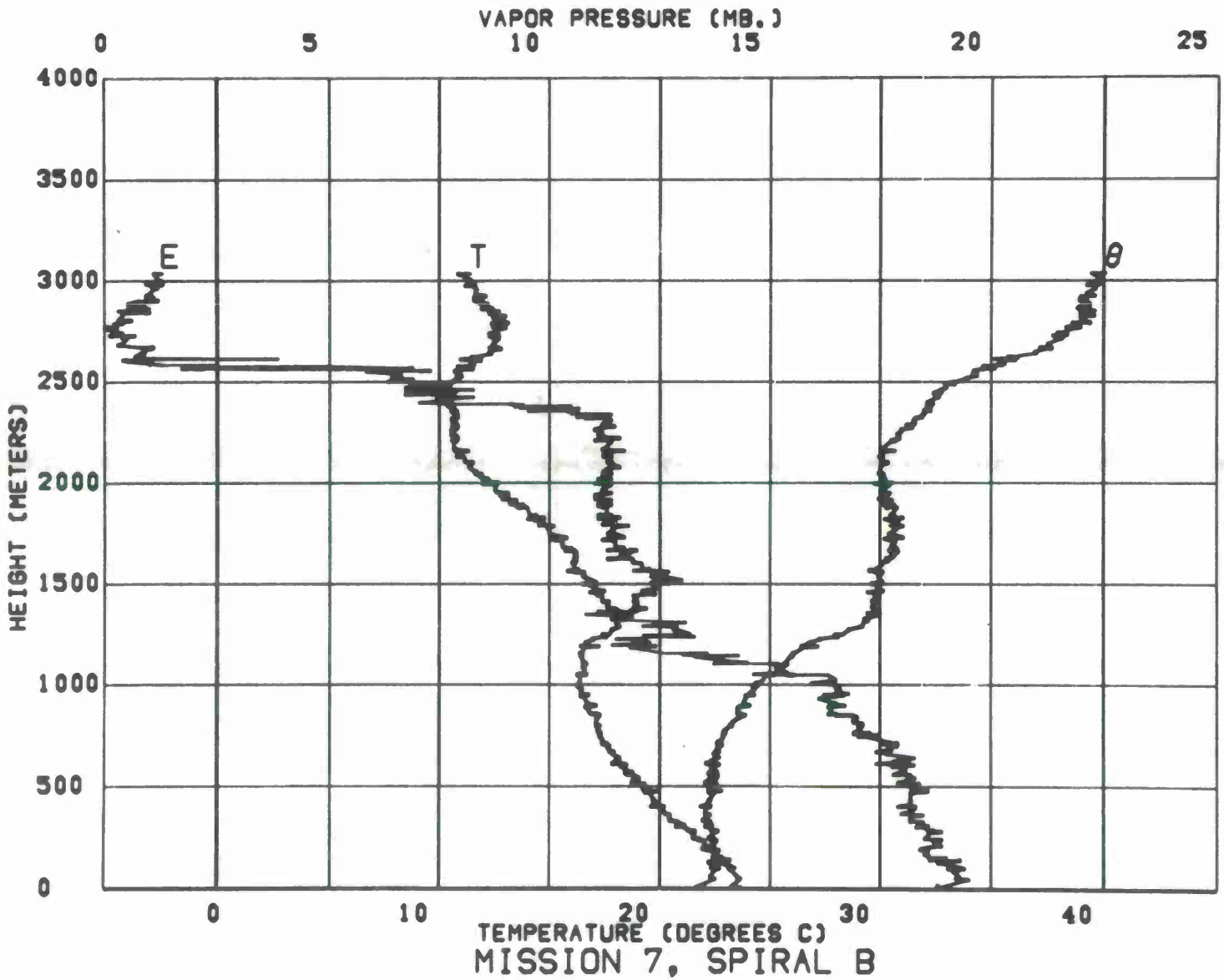
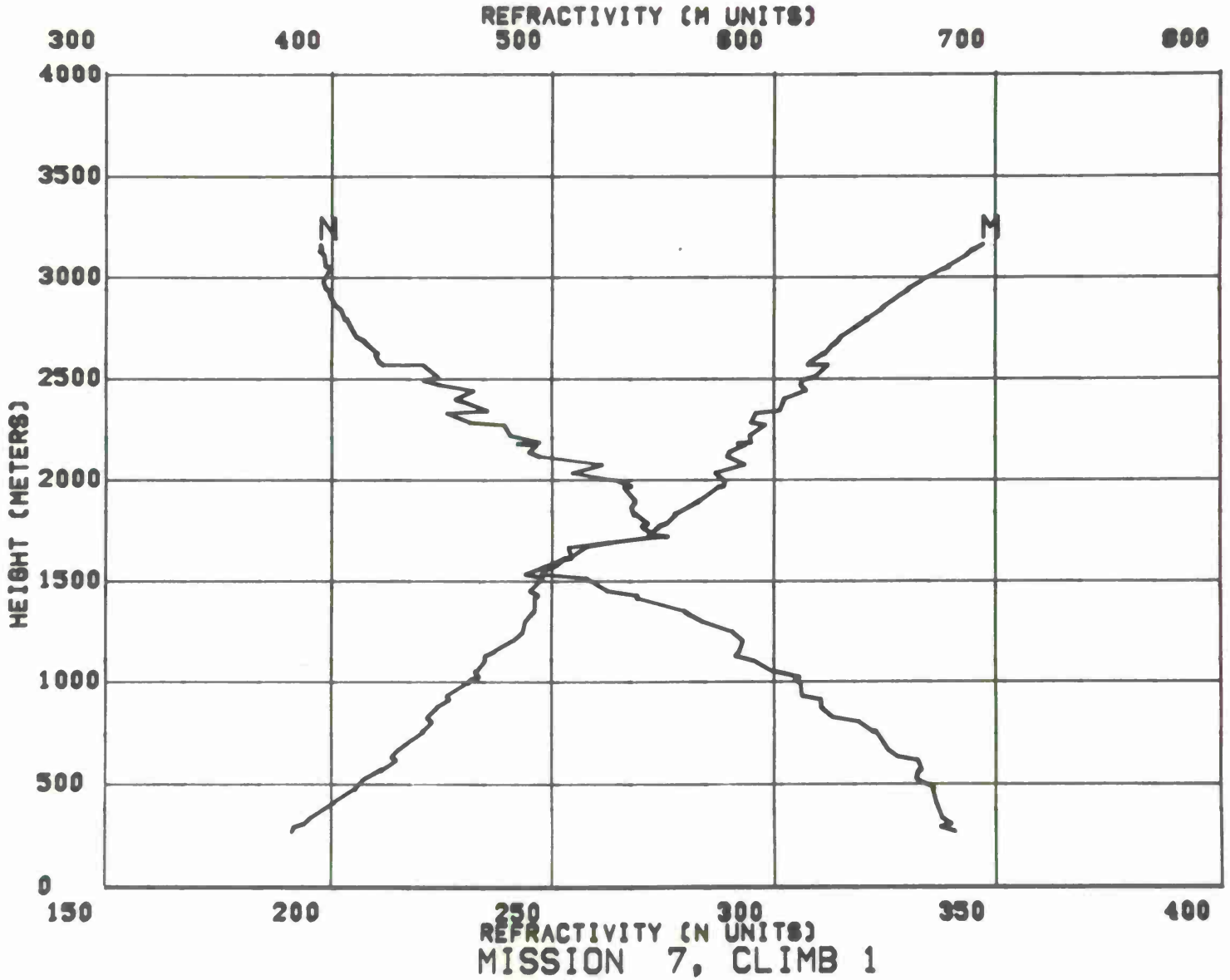
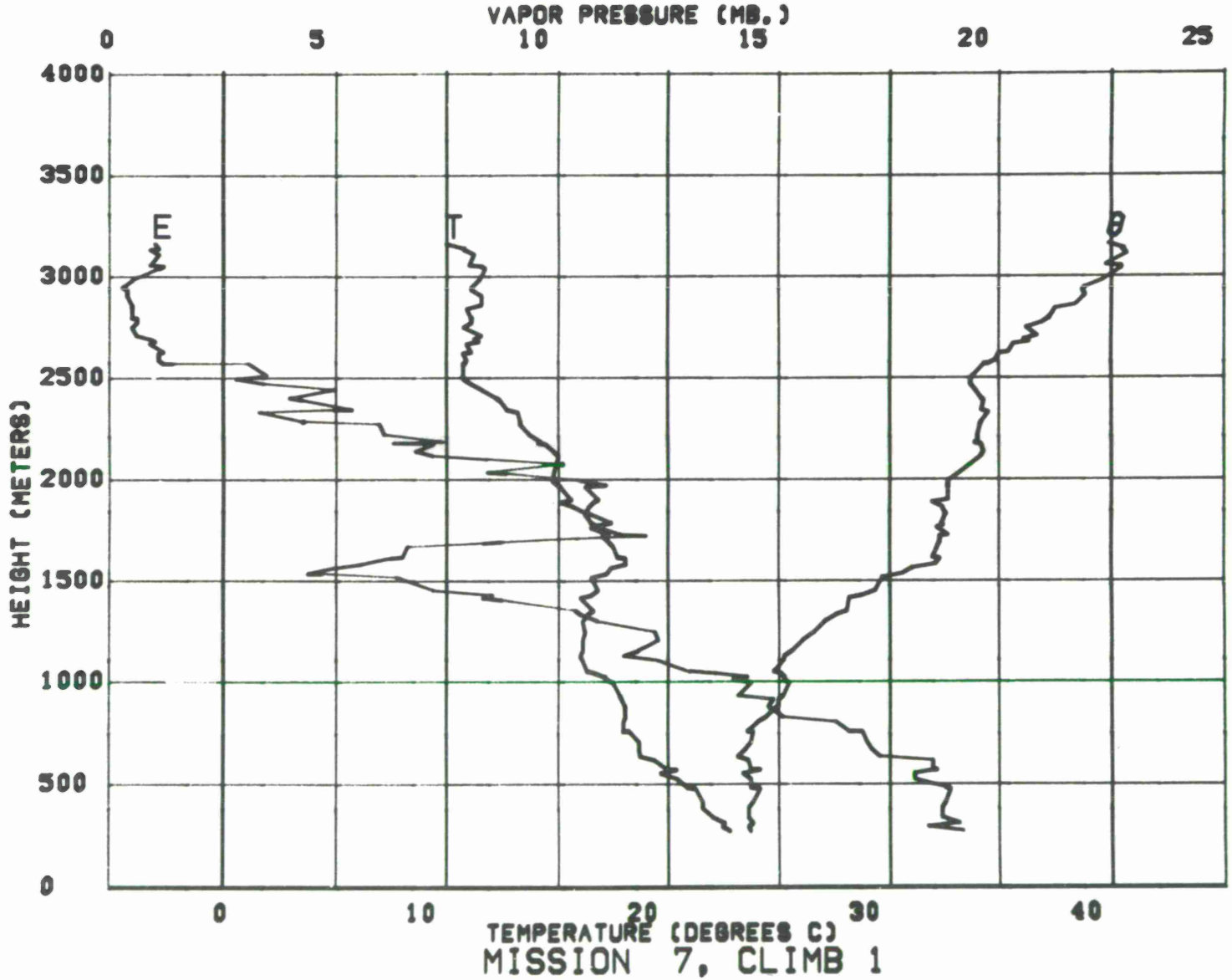
E


REFRACTIVITY (M UNITS)
300
400
500
600
700
800
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
REFRACTIVITY (N UNITS)
150
200
250
300
350
400
M
N
MISSION 7, SPIRAL B

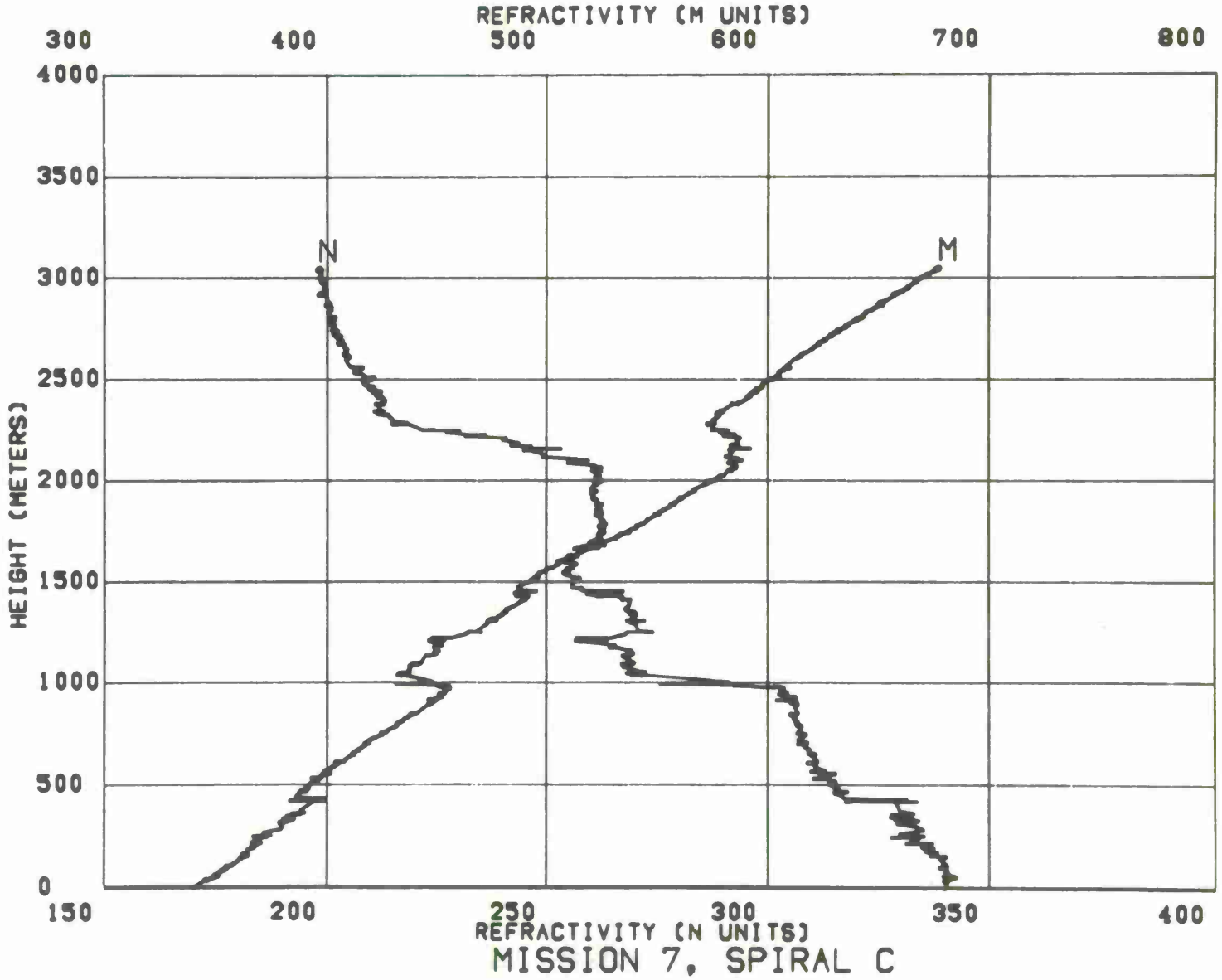


MISSION 7, SPIRAL B

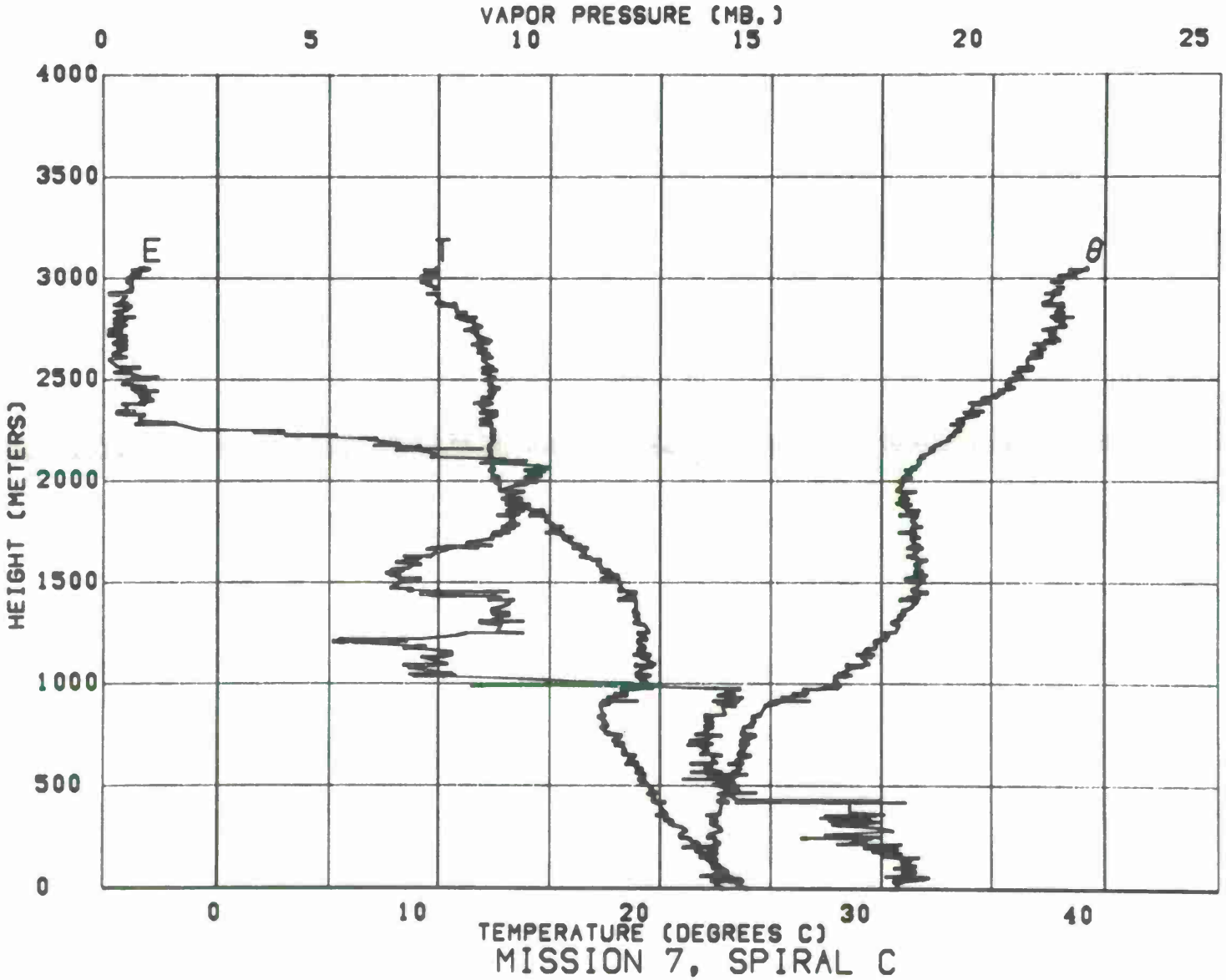

REFRACTIVITY (M UNITS)
300
400
500
600
700
800
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
N
M
150
200
250
300
350
400
REFRACTIVITY (N UNITS)
MISSION 7, CLIMB 1



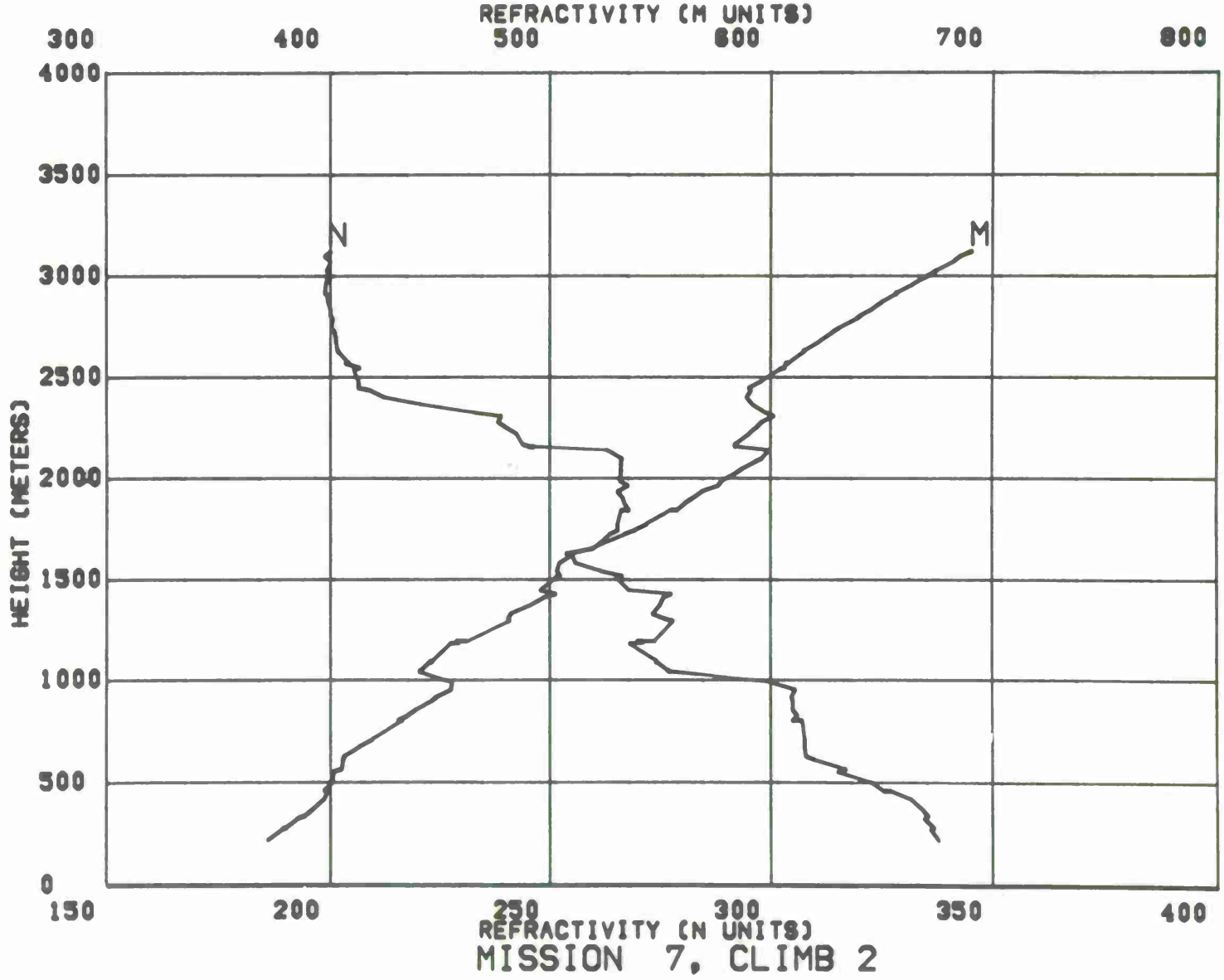
MISSION 7, CLIMB 1



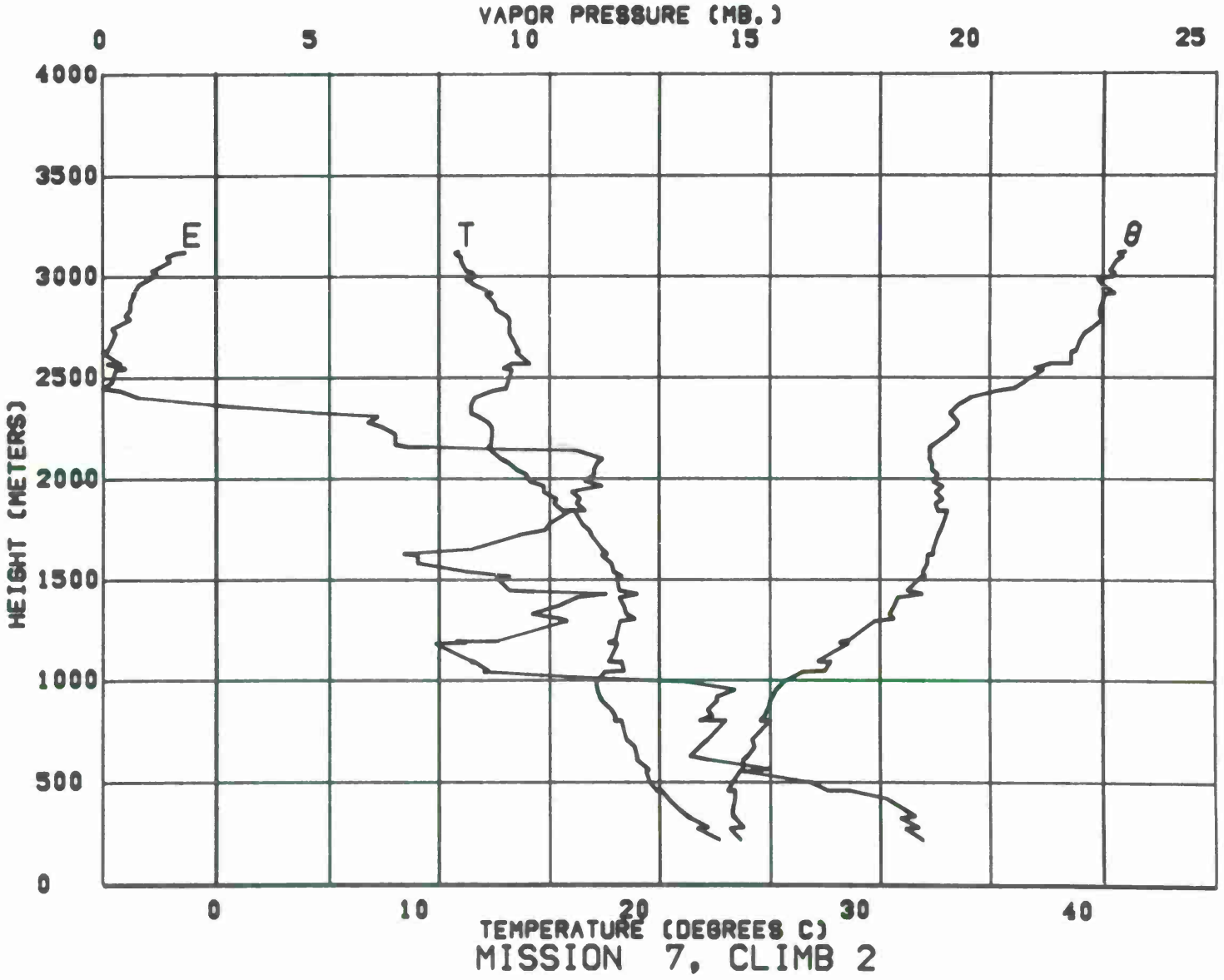
MISSION 7, SPIRAL C



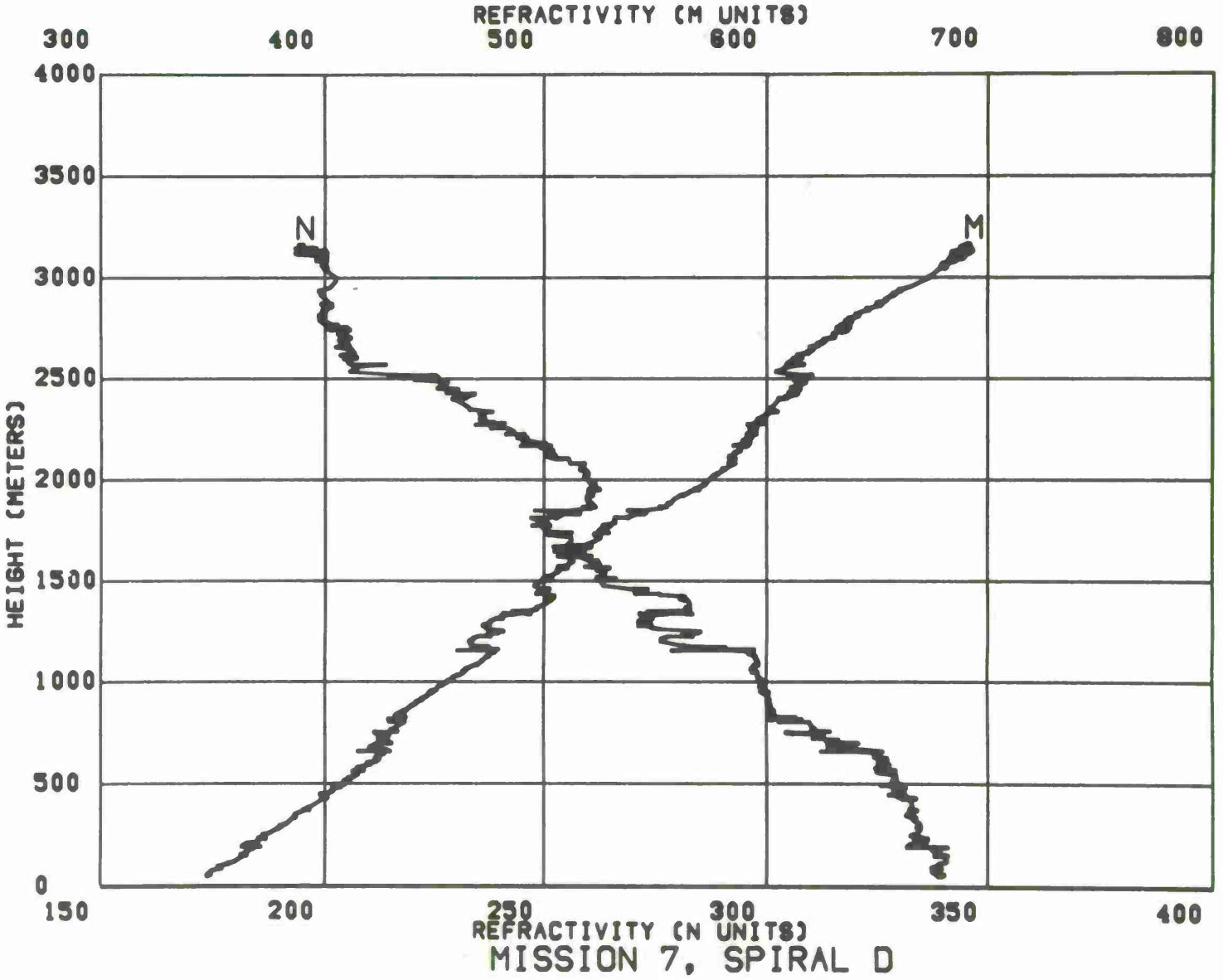
MISSION 7, SPIRAL C



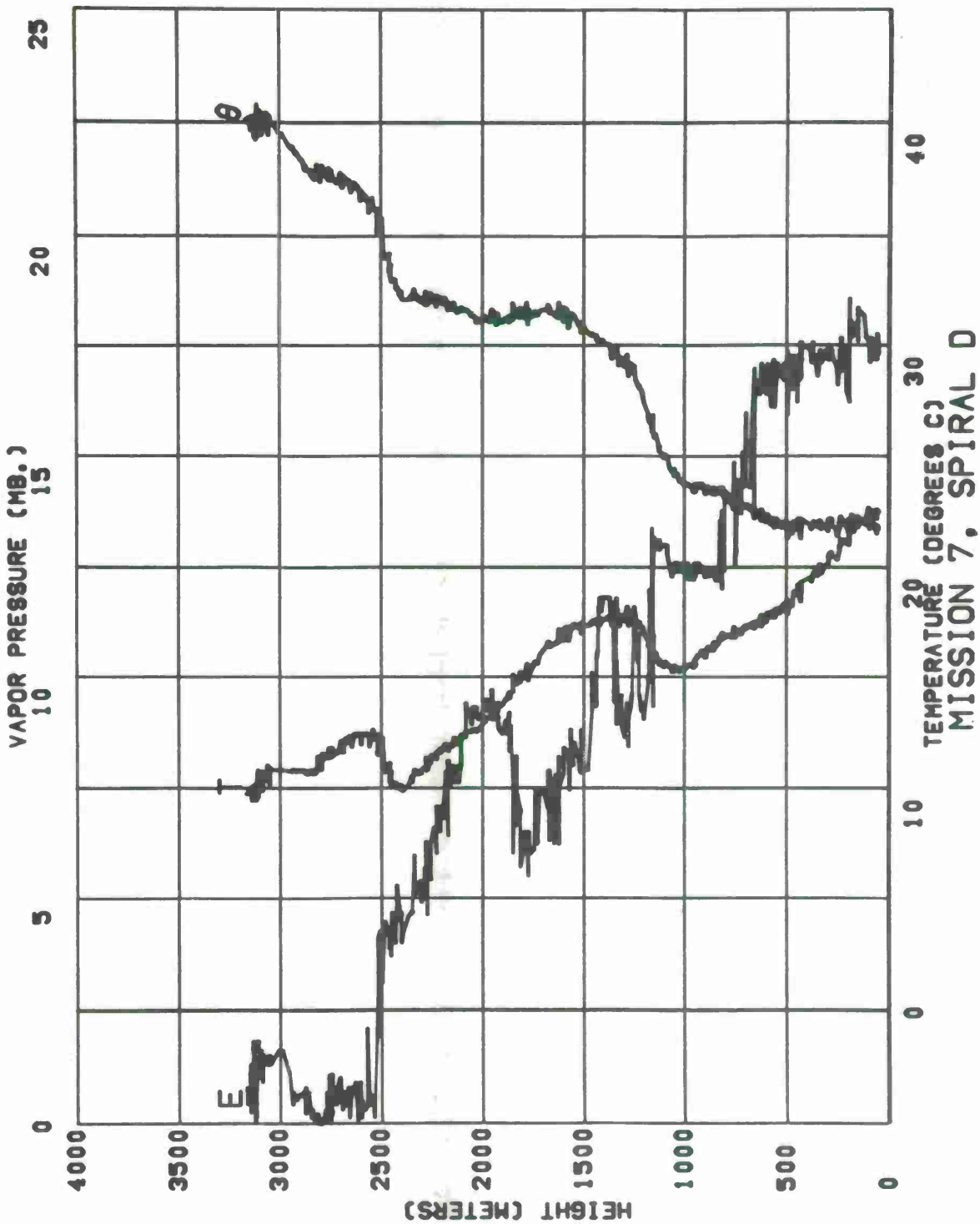
MISSION 7, CLIMB 2



MISSION 7, CLIMB 2



MISSION 7, SPIRAL D


VAPOR PRESSURE (MB.)
0
5
10
15
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25
HEIGHT (METERS)
4000
3500
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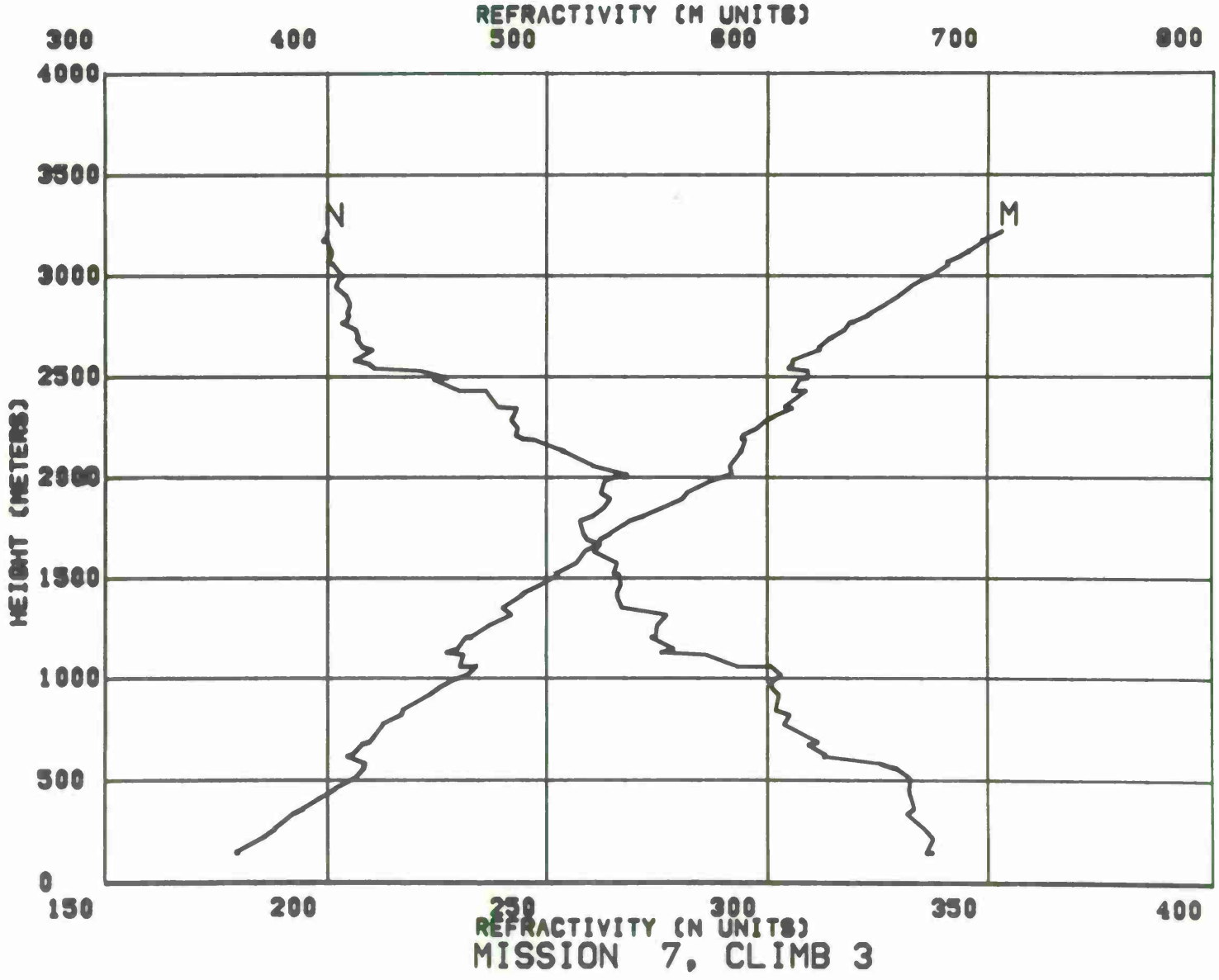
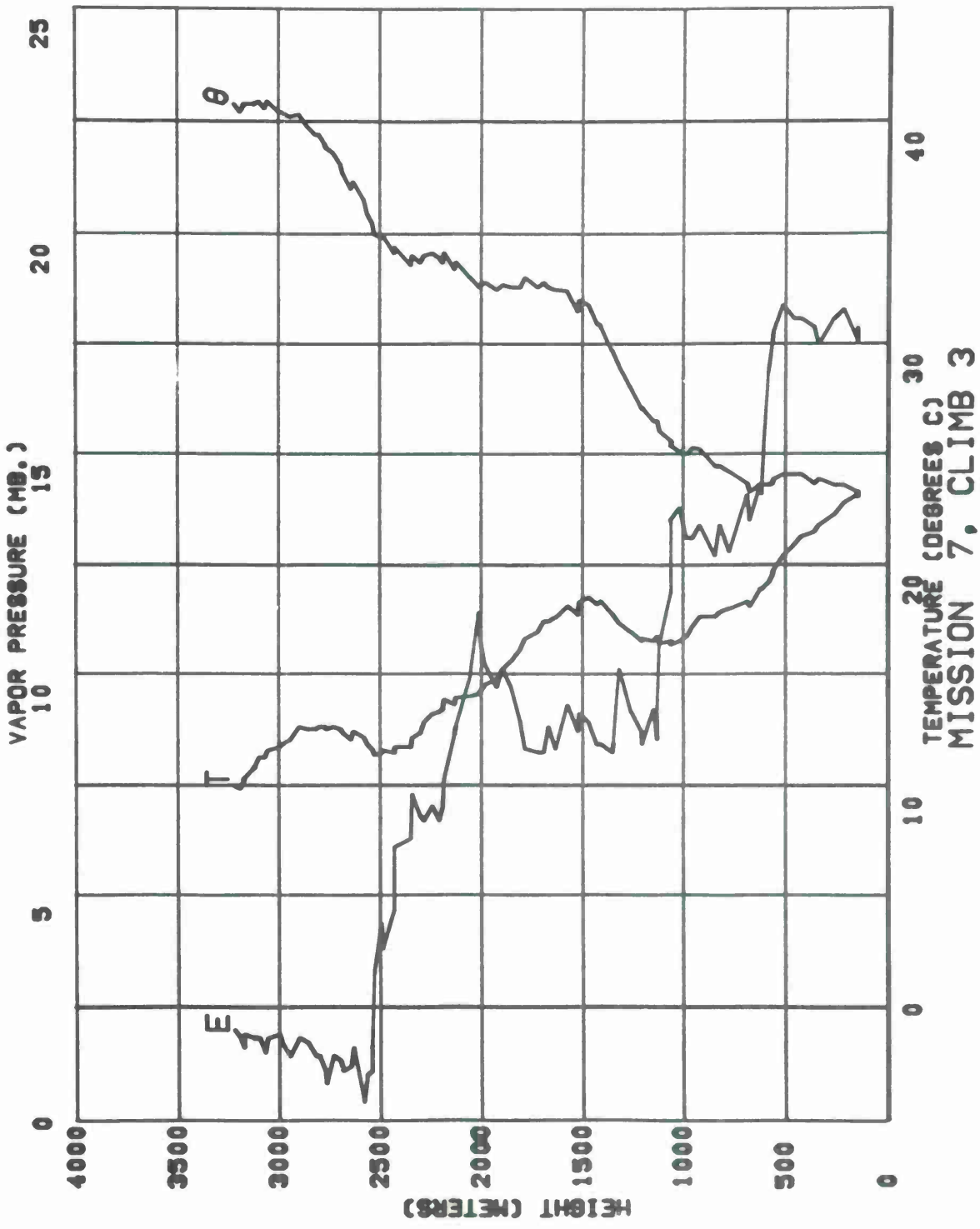
2500
2000
1500
1000
500
0
TEMPERATURE (DEGREES C)
0
10
20
30
40
MISSION 7, SPIRAL D
D
E



MISSION 7, CLIMB 3


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
HEIGHT (METERS)
4000
3500
3000
2500
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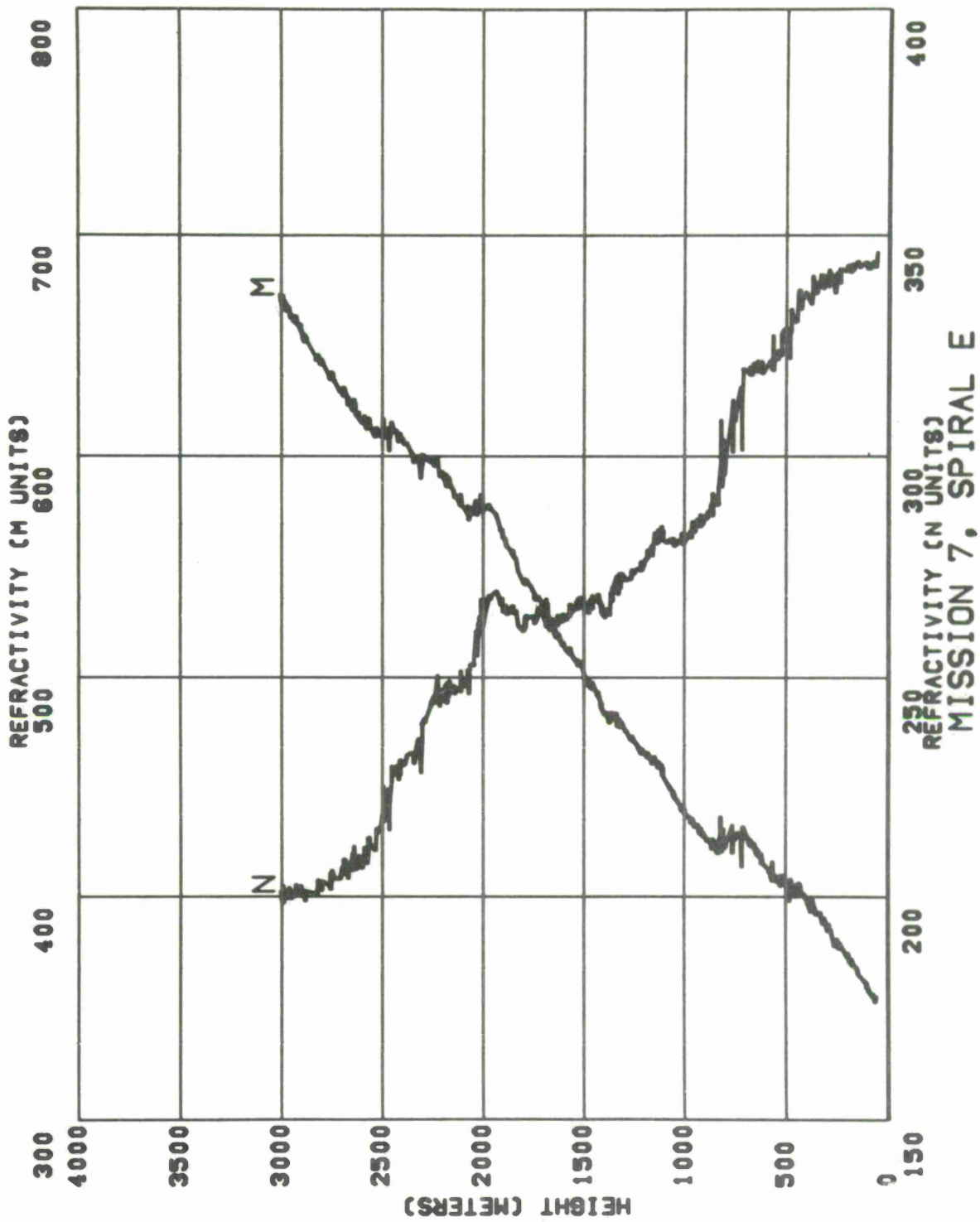
1500
1000
500
0
TEMPERATURE (DEGREES C)
0
10
20
30
40
θ
T
E
MISSION 7, CLIMB 3


REFRACTIVITY (M UNITS)
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700
800
HEIGHT (METERS)
4000
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3000
2500
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1500
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500
0
M
N
REFRACTIVITY (N UNITS)
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200
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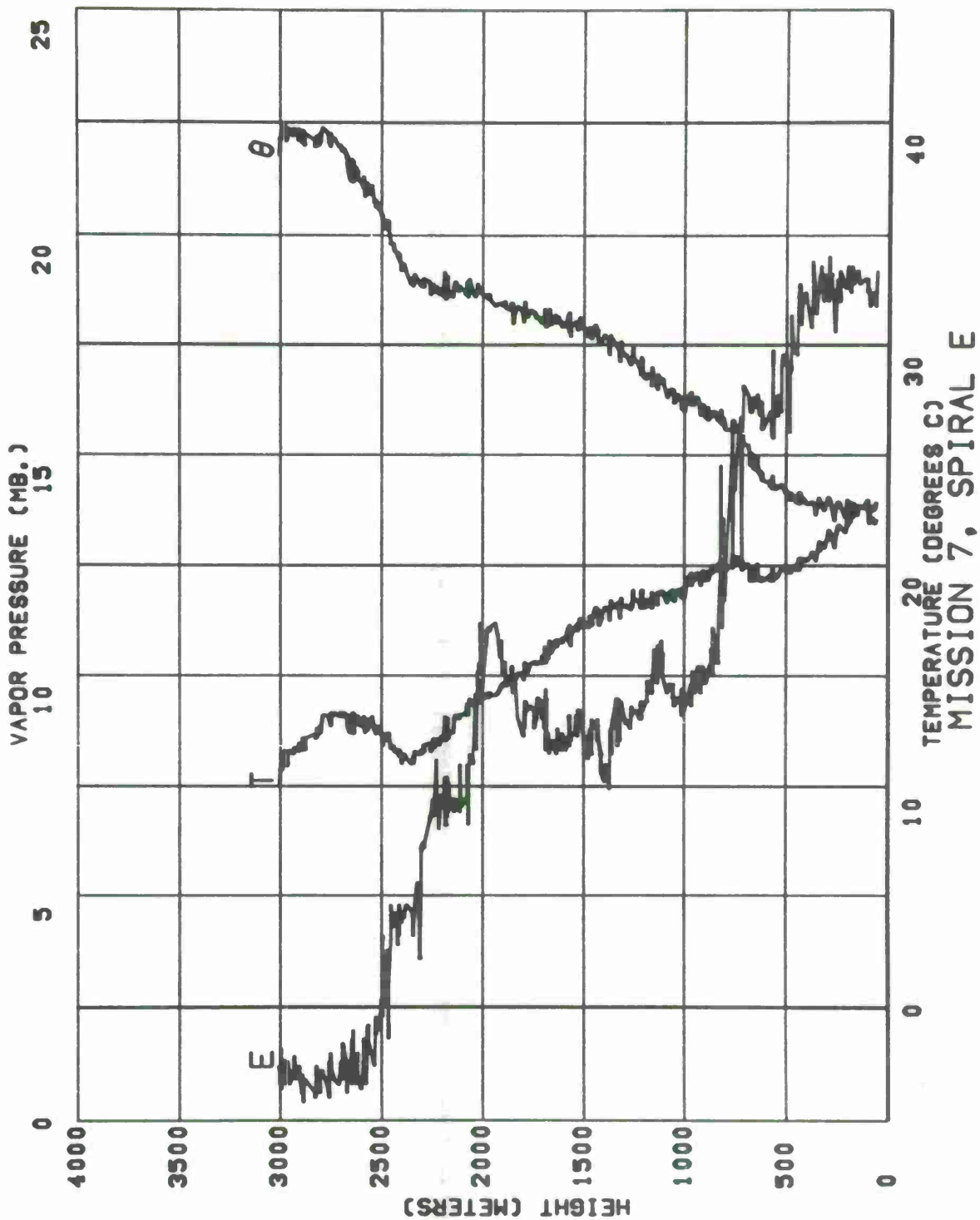
300
350
400
MISSION 7, SPIRAL E


MISSION 7, SPIRAL E
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
VAPOR PRESSURE (MB.)
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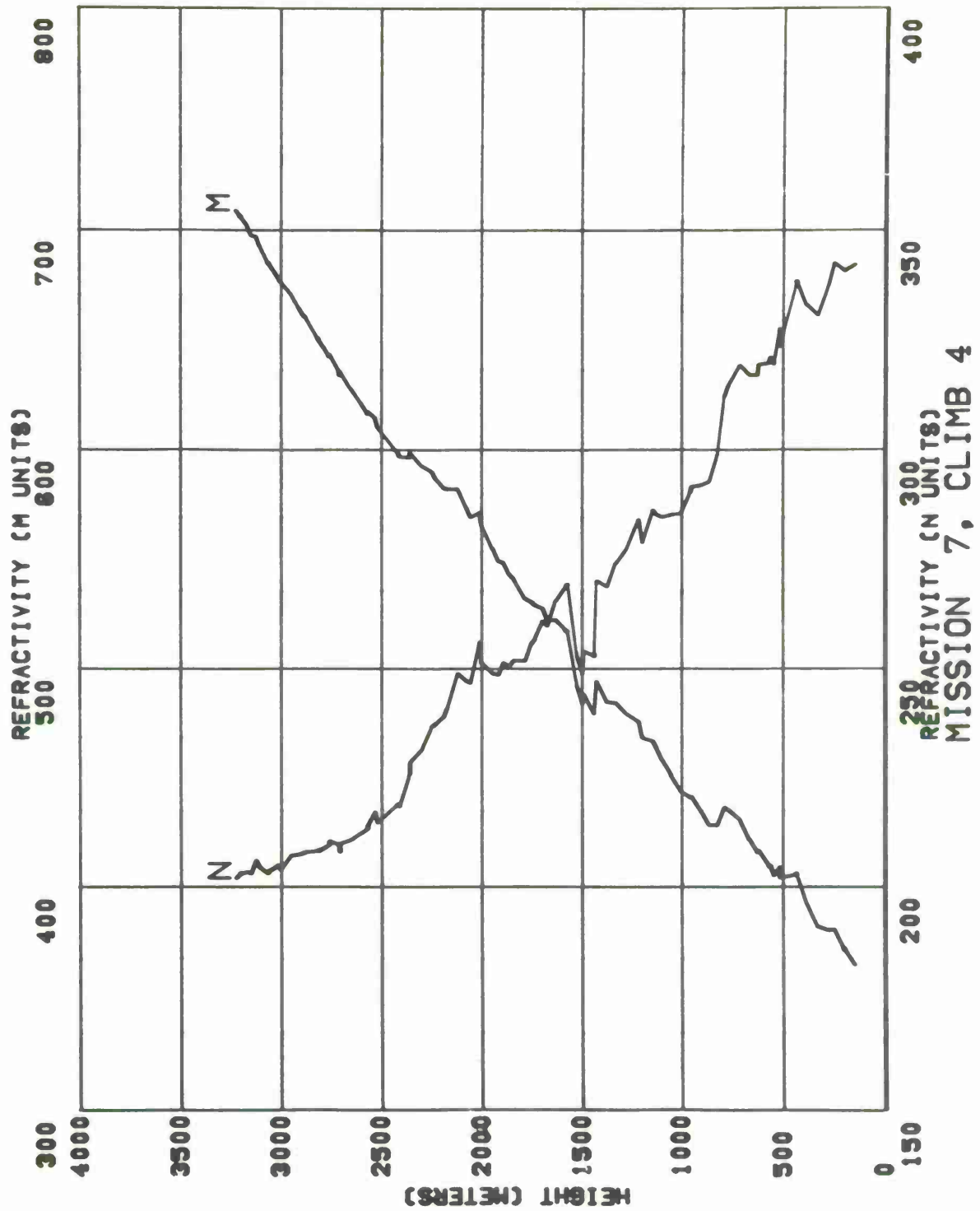
5
10
15
20
25
TEMPERATURE (DEGREES C)
0
10
20
30
40
θ
T
E


REFRACTIVITY (M UNITS)
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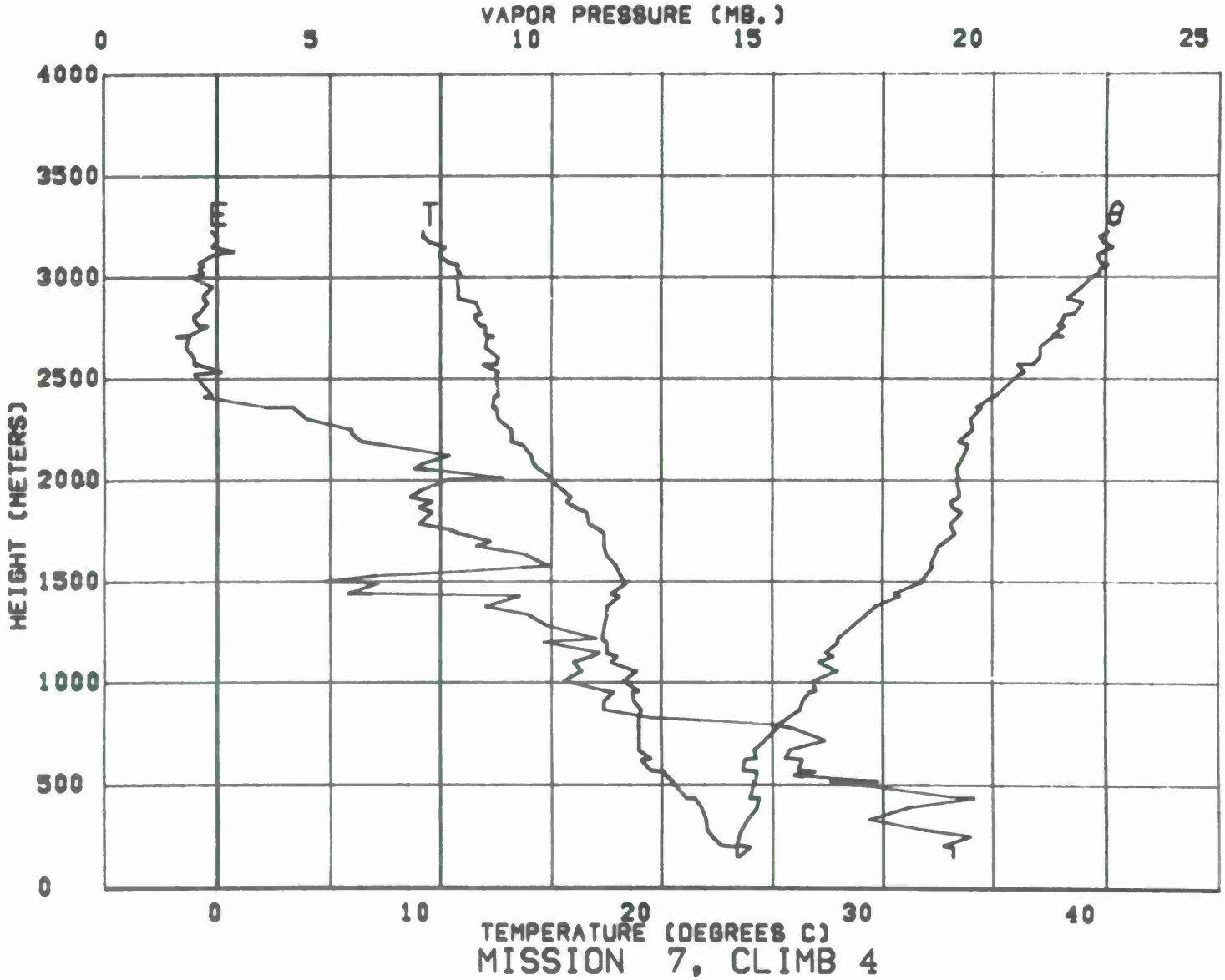
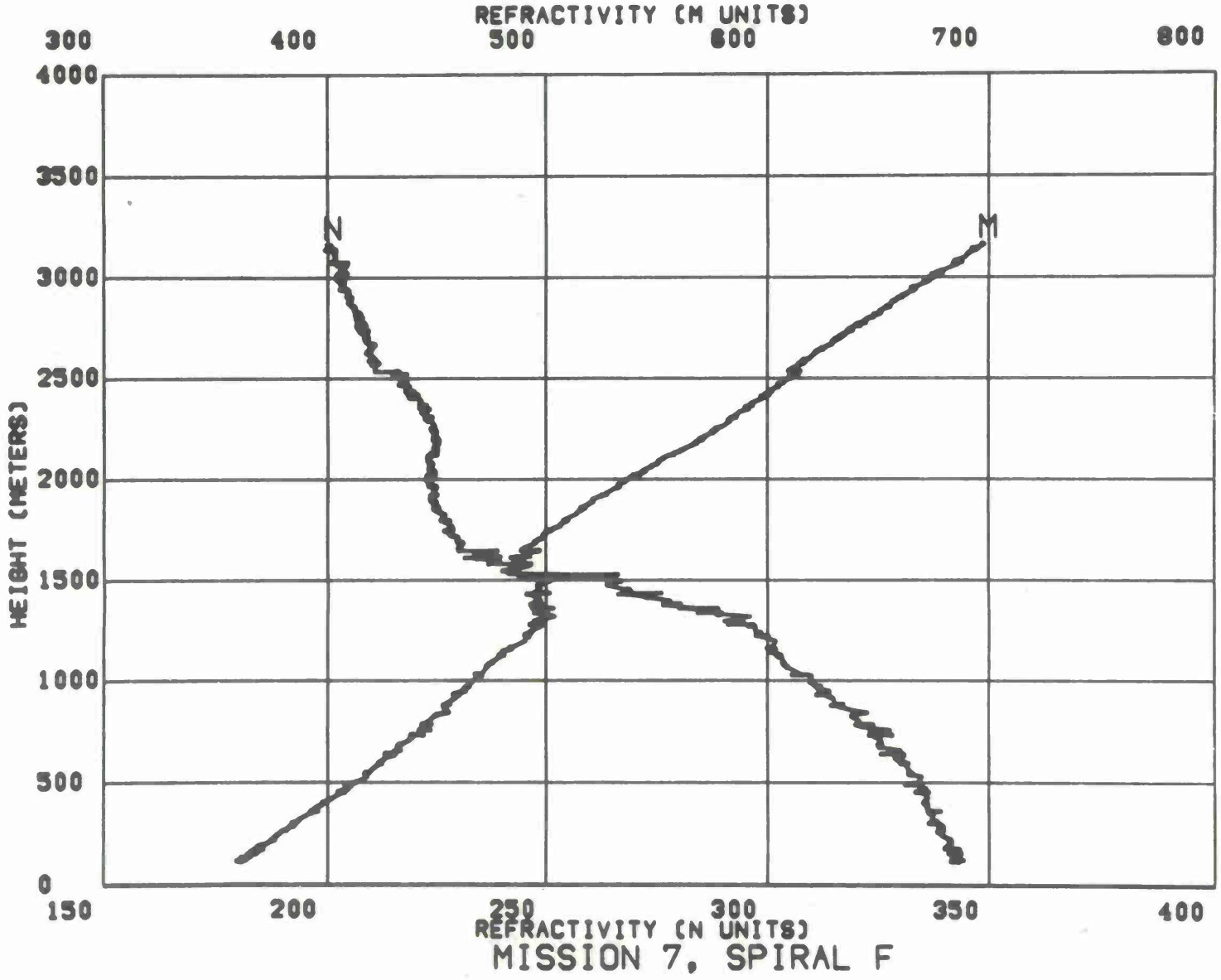
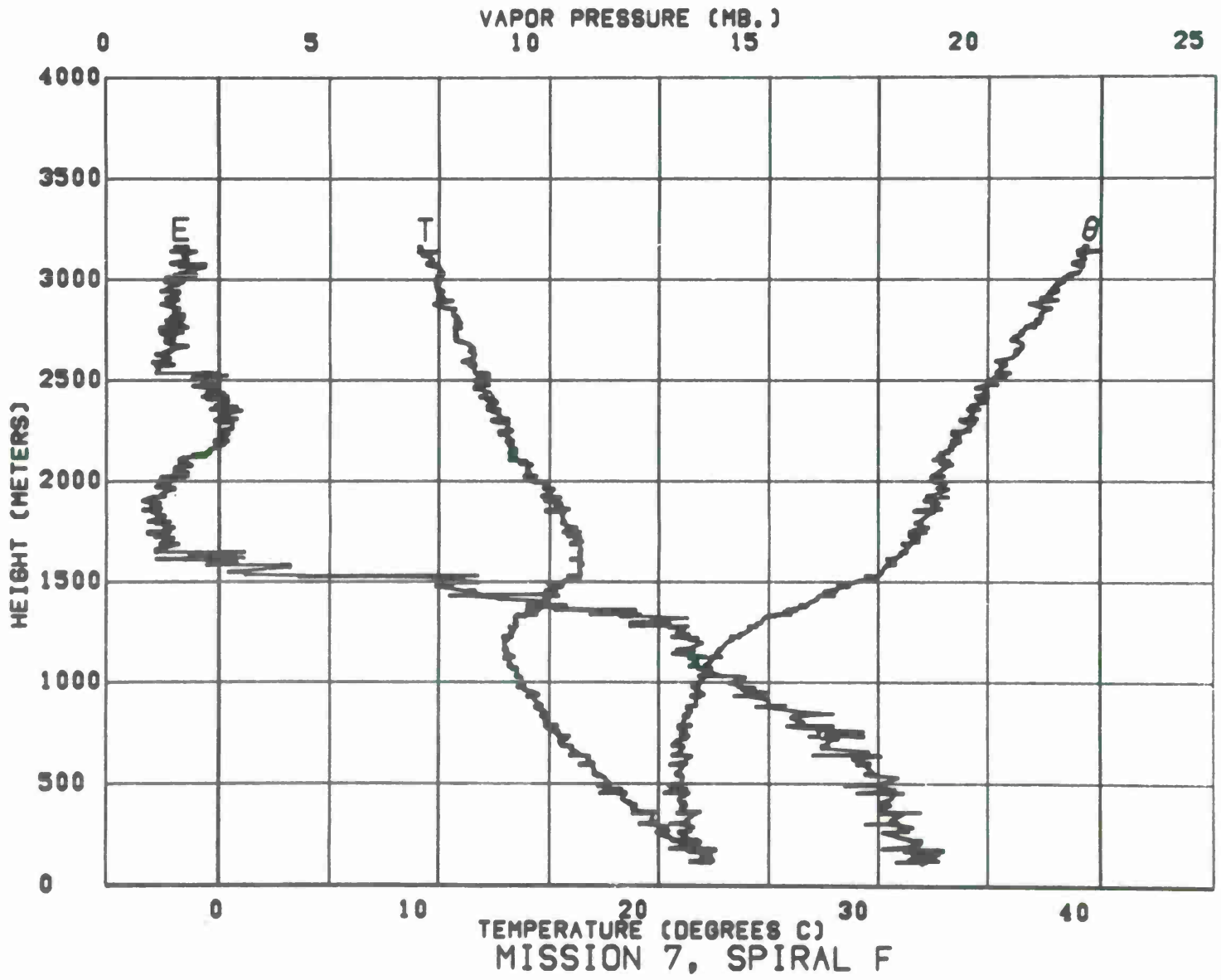
700
600
500
400
300
REFRACTIVITY (N UNITS)
400
350
300
250
200
150
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
M
N
MISSION 7, CLIMB 4



MISSION 7, CLIMB 4



MISSION 7, SPIRAL F



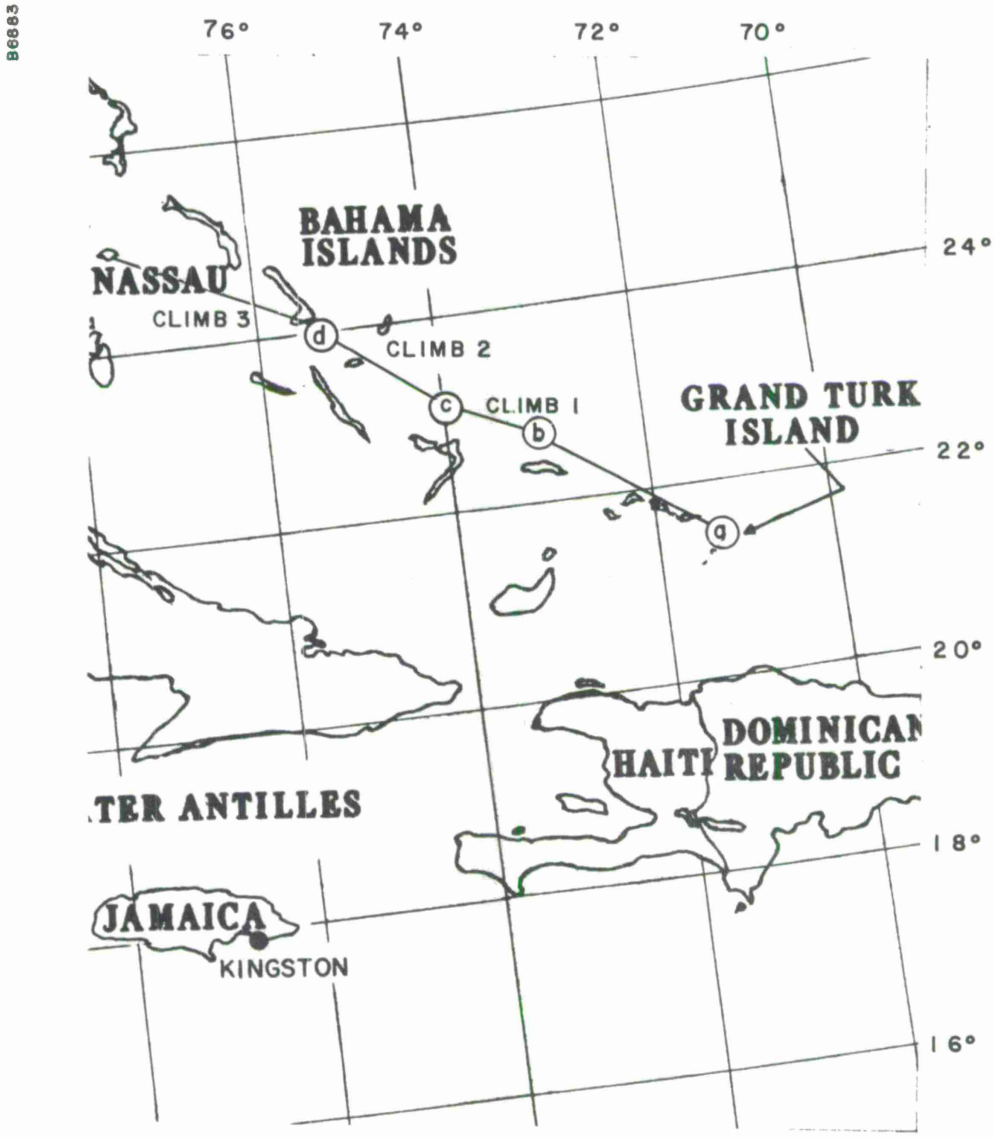
MISSION 7, SPIRAL F

MISSION NO. 8

Date: 18 March 1969

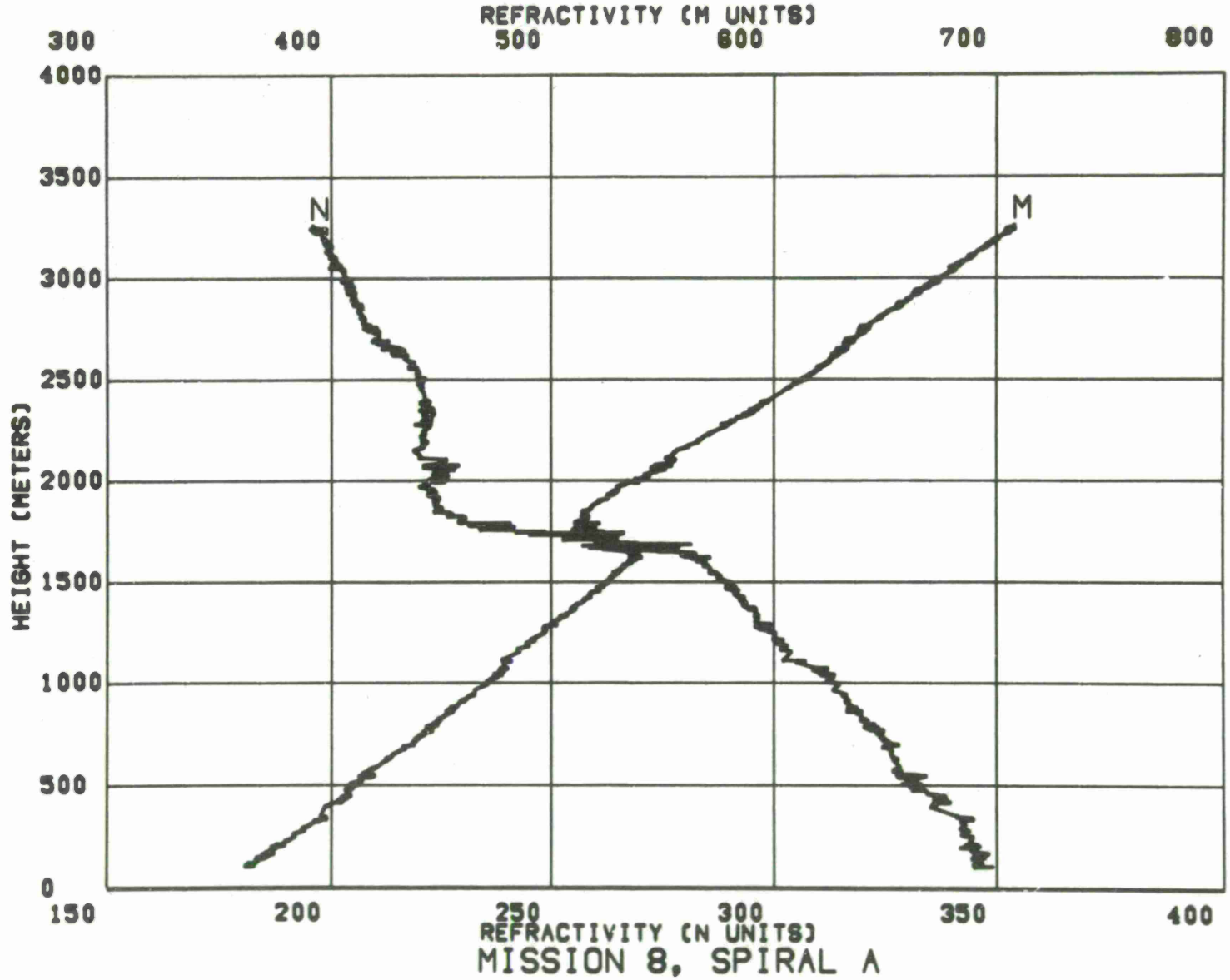
Data were obtained on four spirals and three ascents along Flight Path VII, from Grand Turk Island to Nassau, Bahamas.

Spiral	Location	Spiral Start Time Z	Local
A	a. Grand Turk	1447	0947
B	b. 22-35 N, 73-07 W	1547	1047
Climb 1	b-c	1606	1106
C	c. 23-08 N, 74-00 W	1630	1130
Climb 2	c-d	1650	1150
D	d. 24-00 N, 75-35 W	1723	1223
Climb 3	d. Nassau	1741	1241

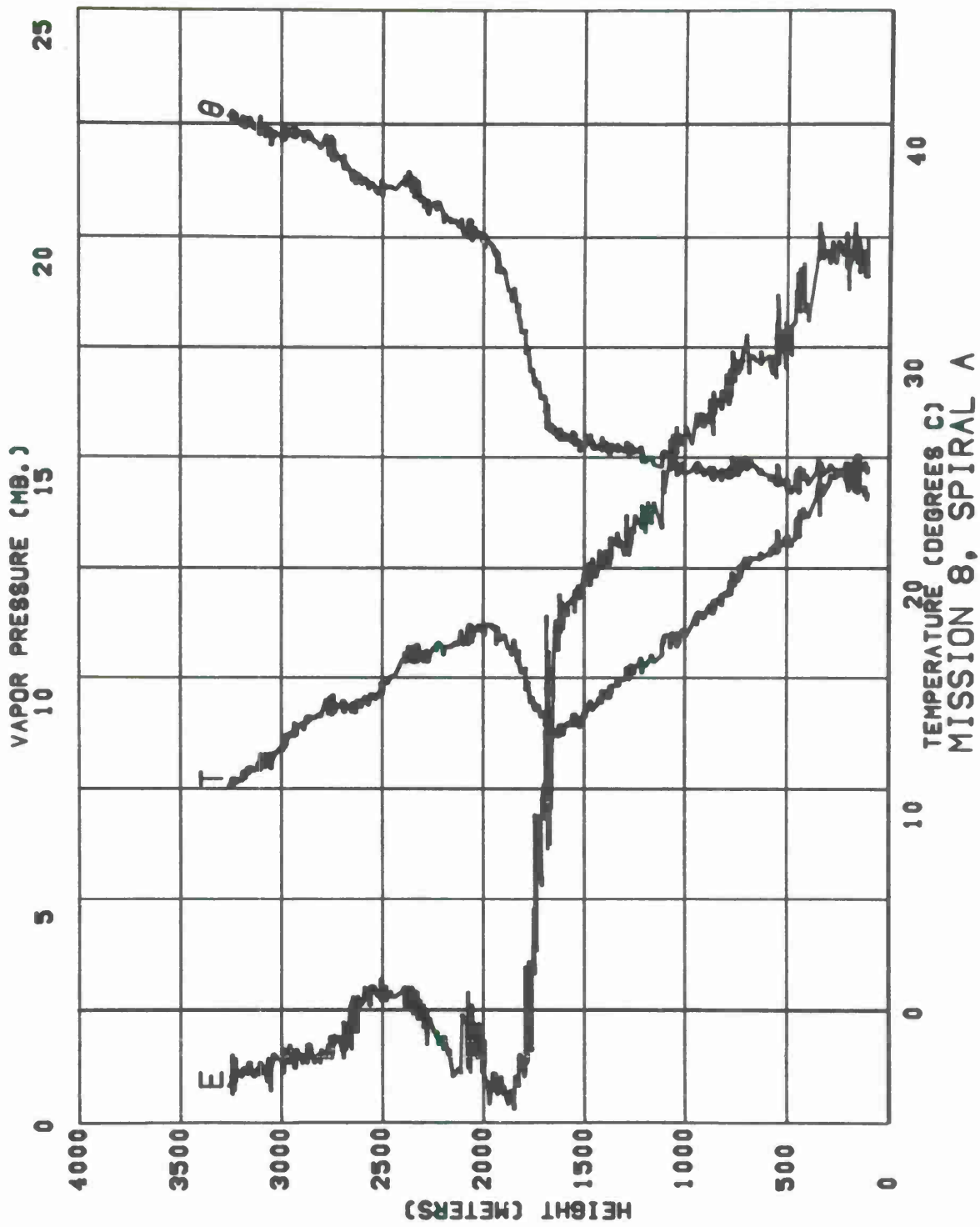


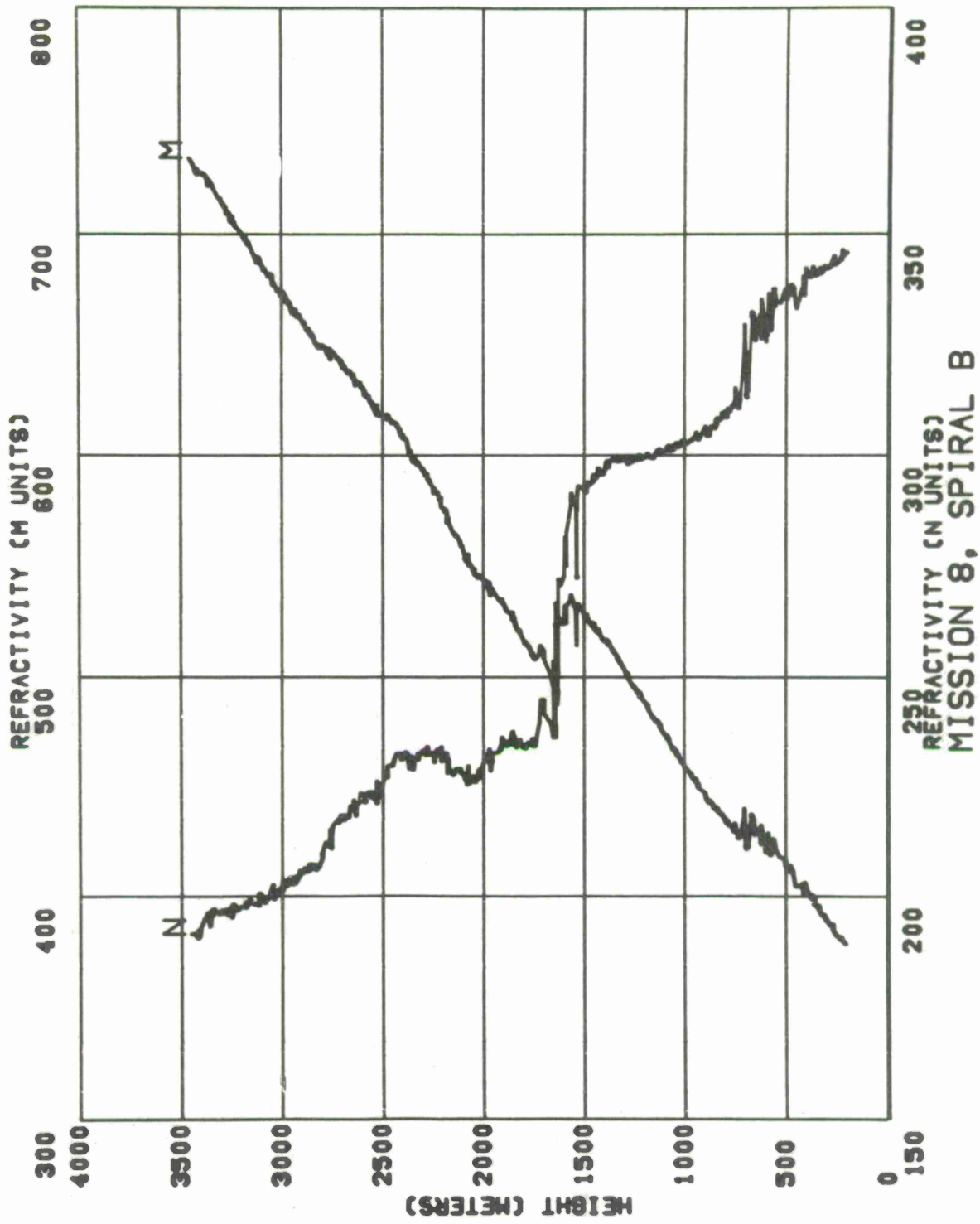
FLIGHT PATH VII

MISSION 8 — 18 MARCH 1969



MISSION 8, SPIRAL A


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
TEMPERATURE (DEGREES C)
0
10
20
30
40
θ
T
E
MISSION 8, SPIRAL A


MISSION 8, SPIRAL B
REFRACTIVITY (M UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
M
N
800
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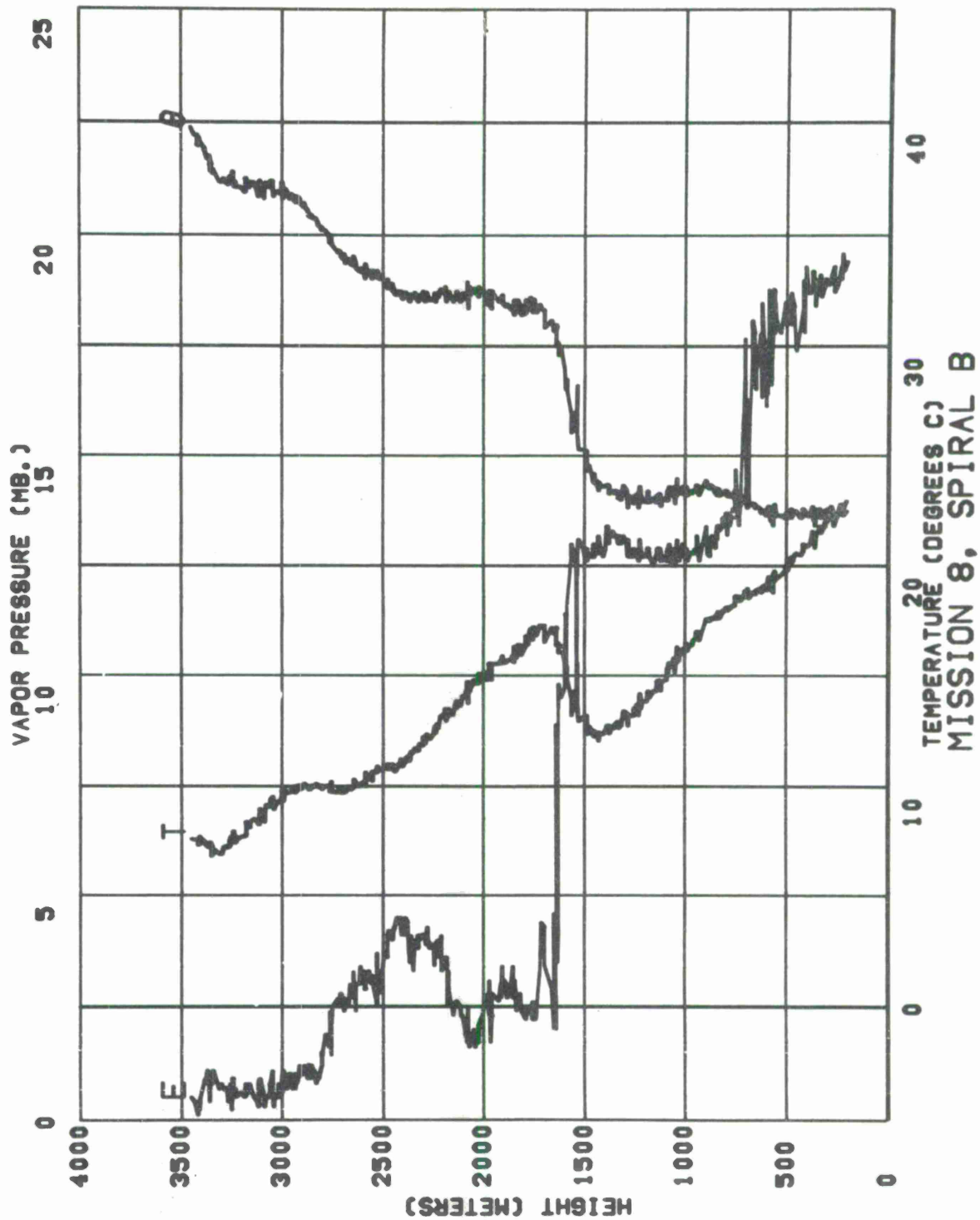
300
400
350
300
250
200
150
4000
3500
3000
2500
2000
1500
1000
500
0


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
TEMPERATURE (DEGREES C)
-20
-10
0
10
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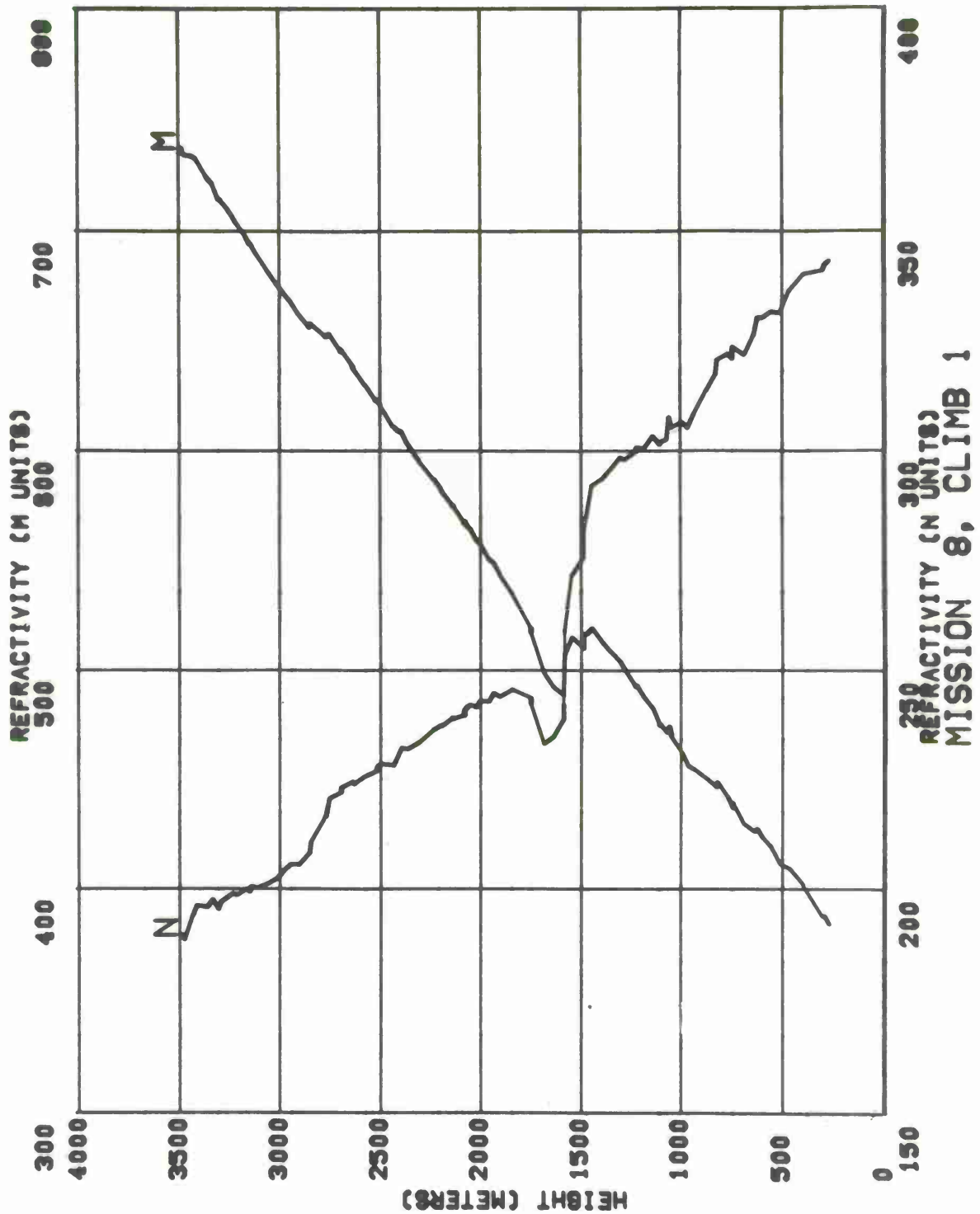
D
T
E
MISSION 8, SPIRAL B


MISSION 8, CLIMB 1
M
N
REFRACTIVITY (N UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
300
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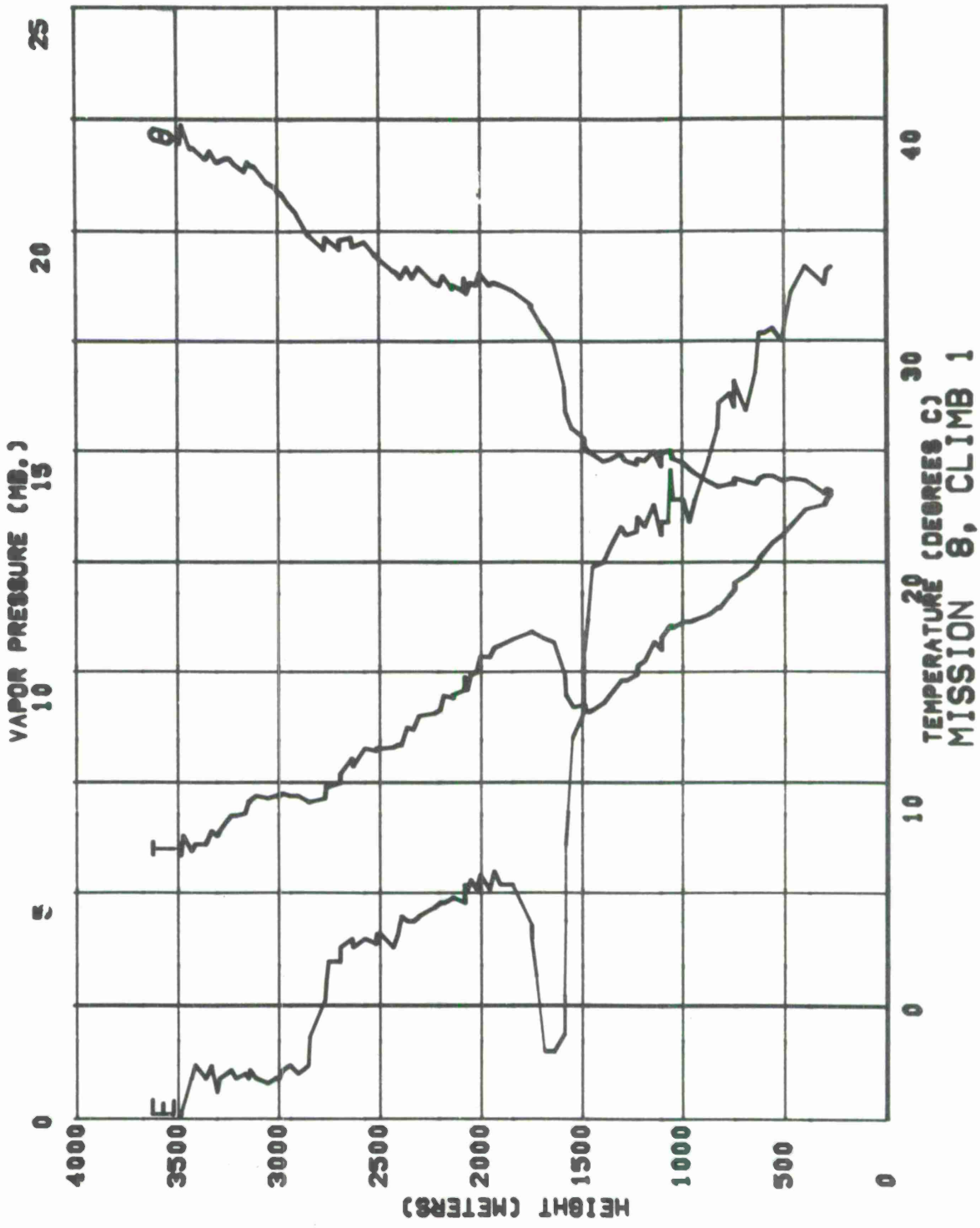
600
700
800
150
200
250
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
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500
0
TEMPERATURE (DEGREES C)
0
10
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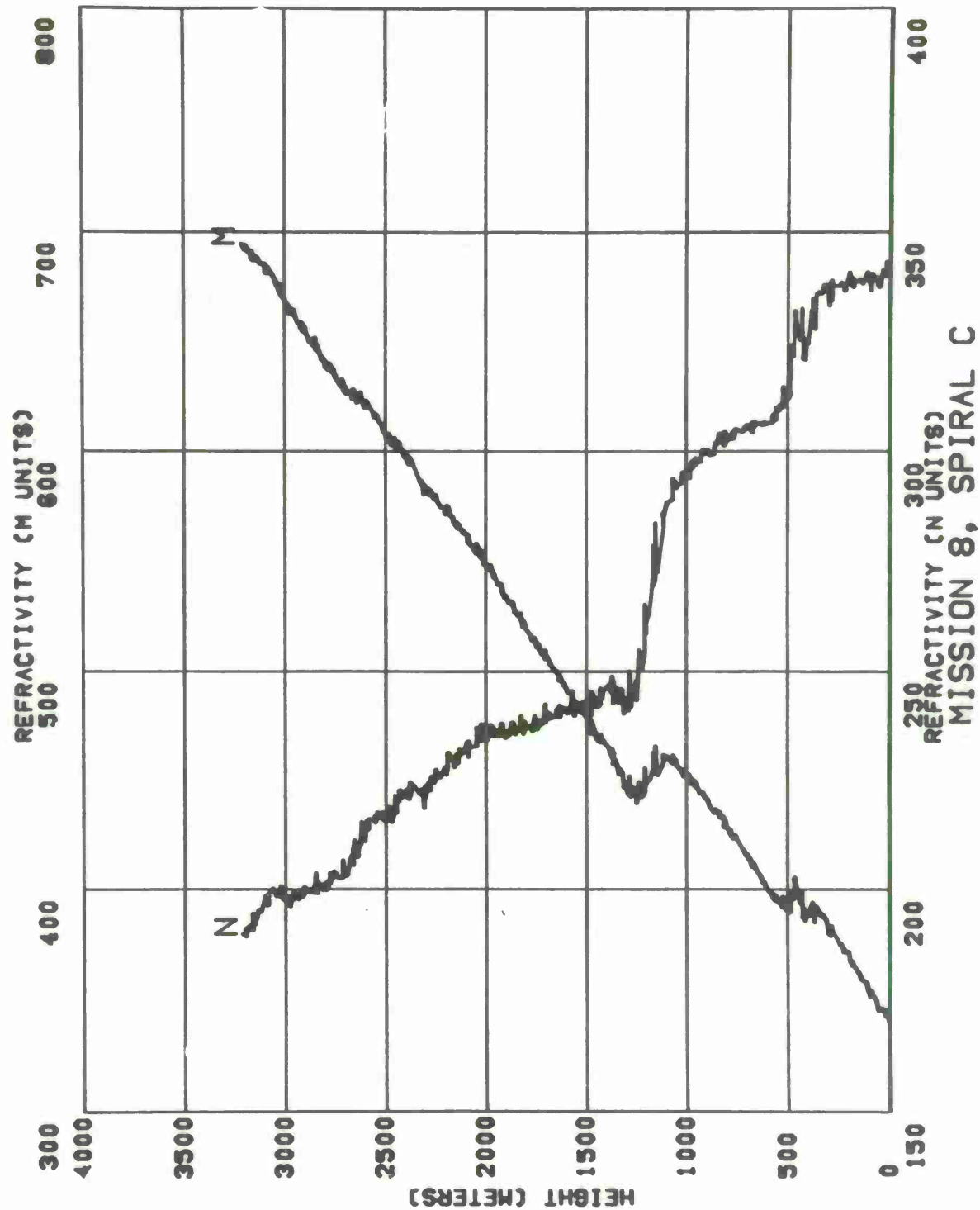
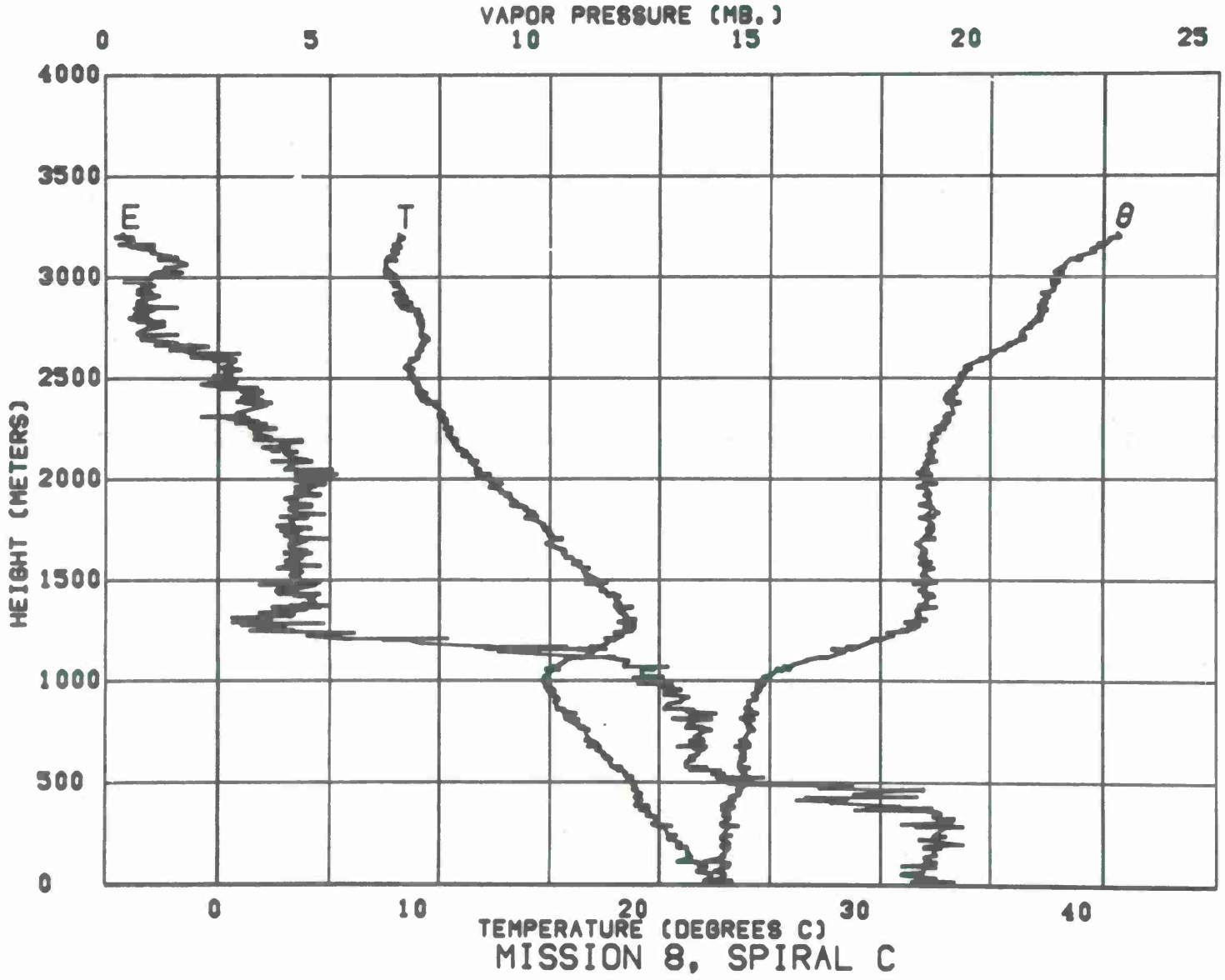
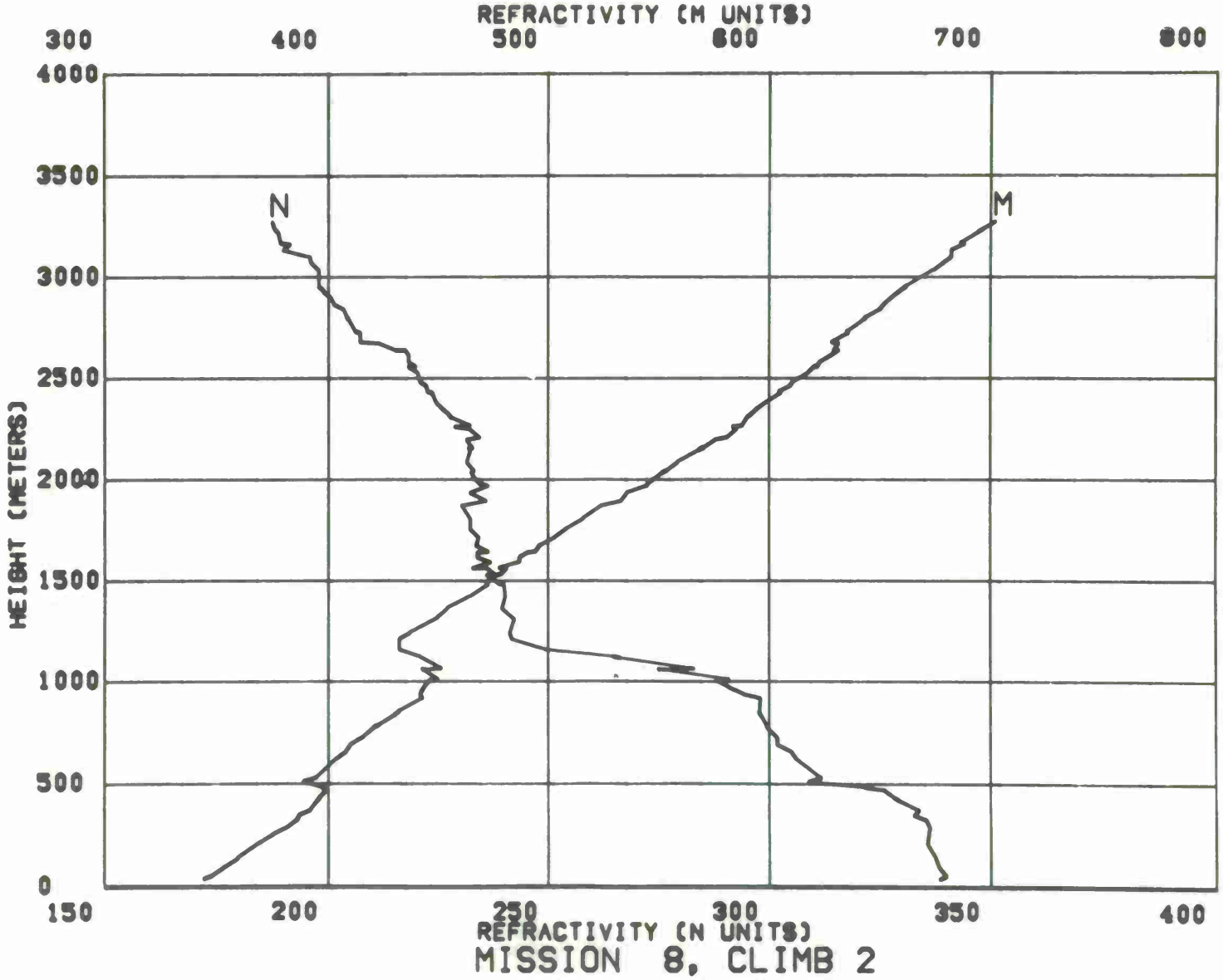
T
E
MISSION 8, CLIMB 1

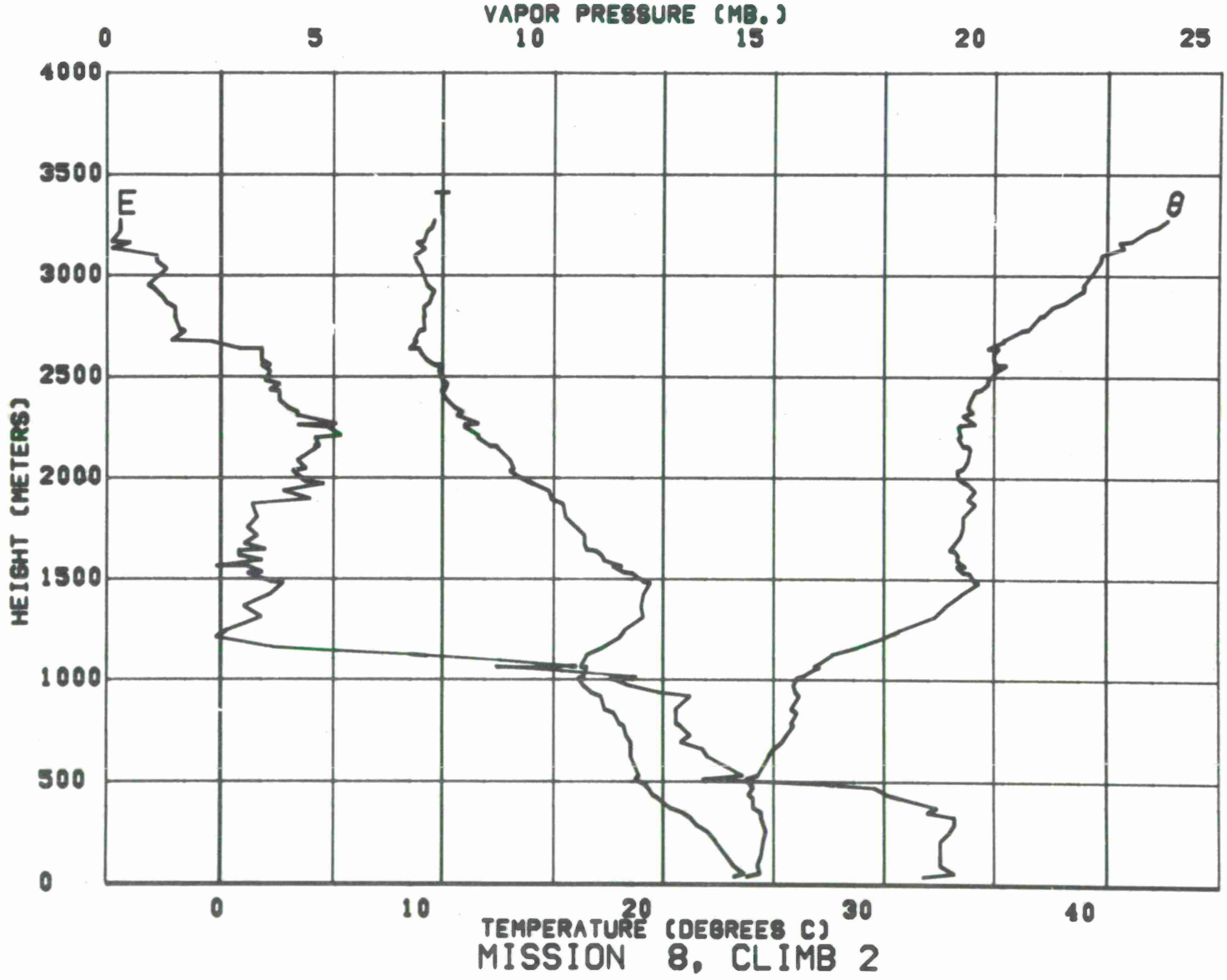

MISSION 8, SPIRAL C
REFRACTIVITY (N UNITS)
REFRACTIVITY (M UNITS)
HEIGHT (METERS)
M
N
300
400
500
600
700
800
150
200
250
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000



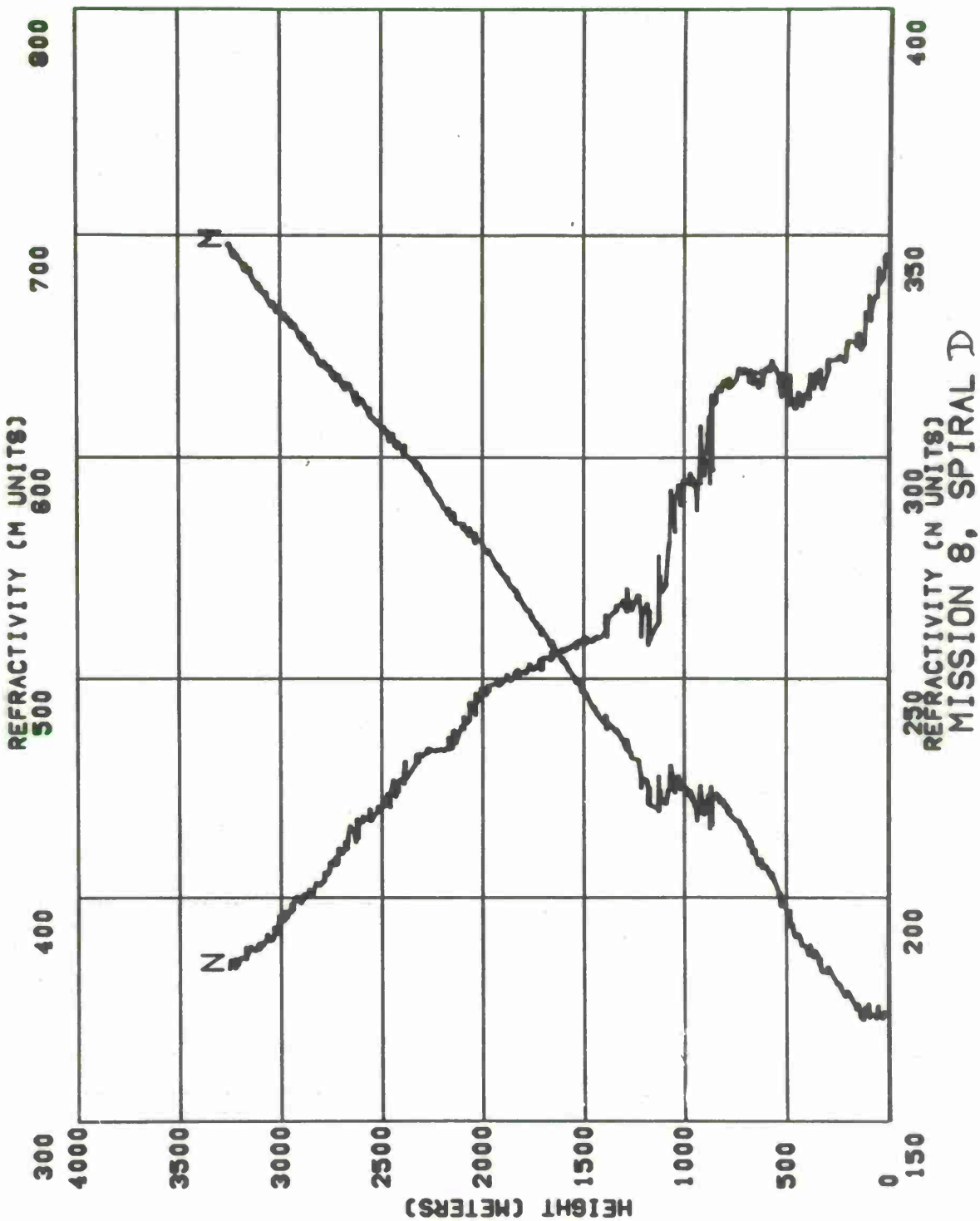
MISSION 8, SPIRAL C



MISSION 8, CLIMB 2



MISSION 8, CLIMB 2


REFRACTIVITY (M UNITS)
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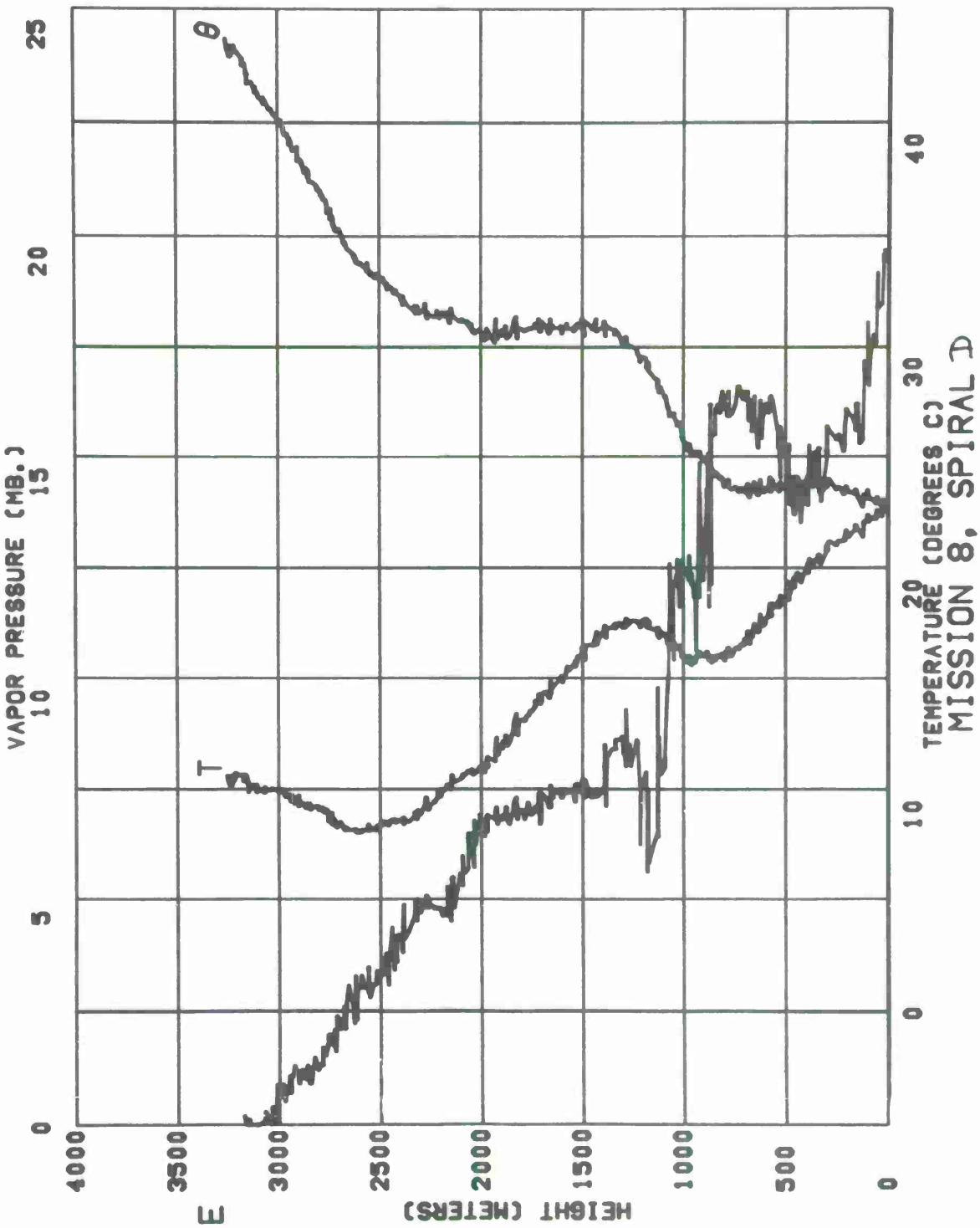
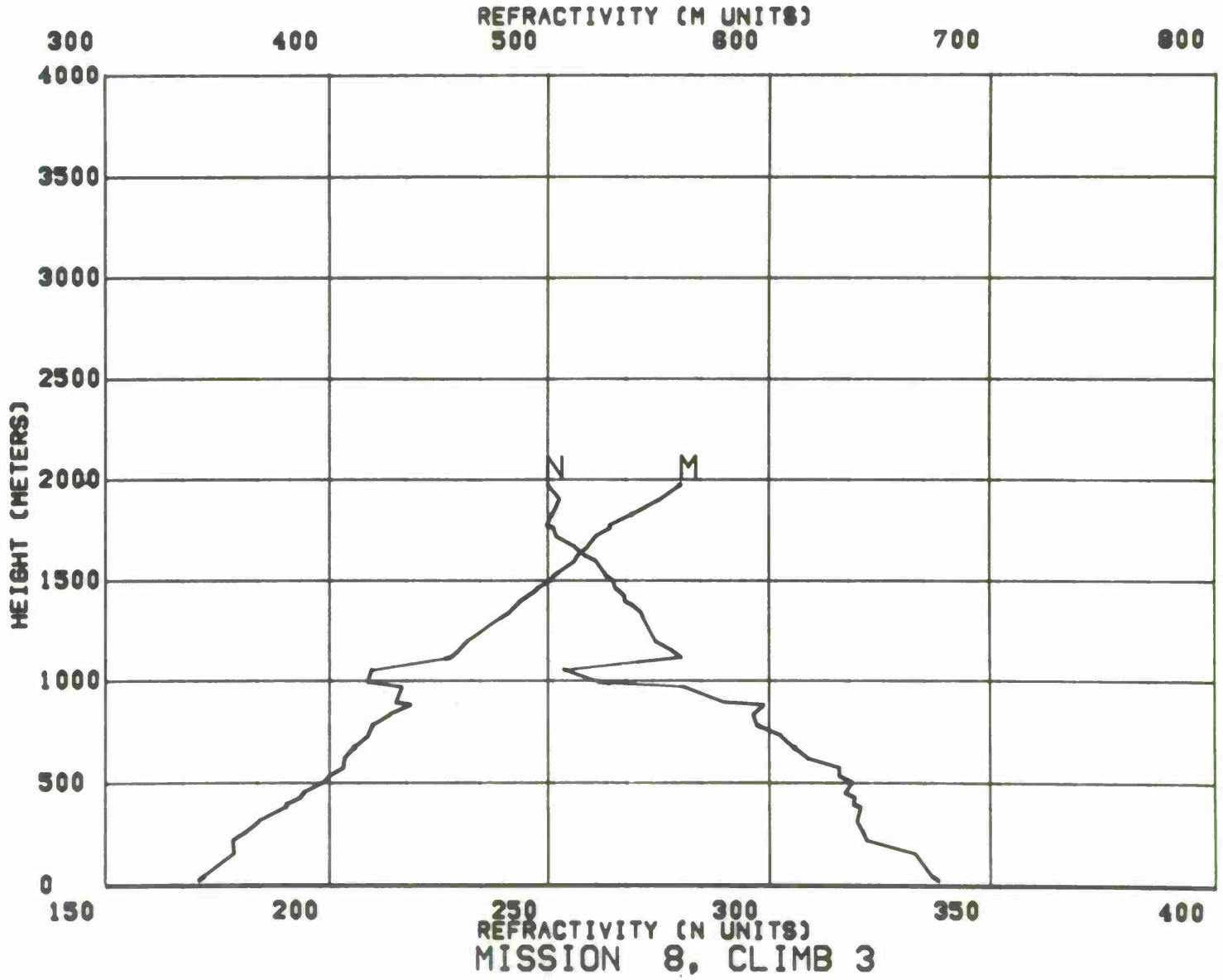
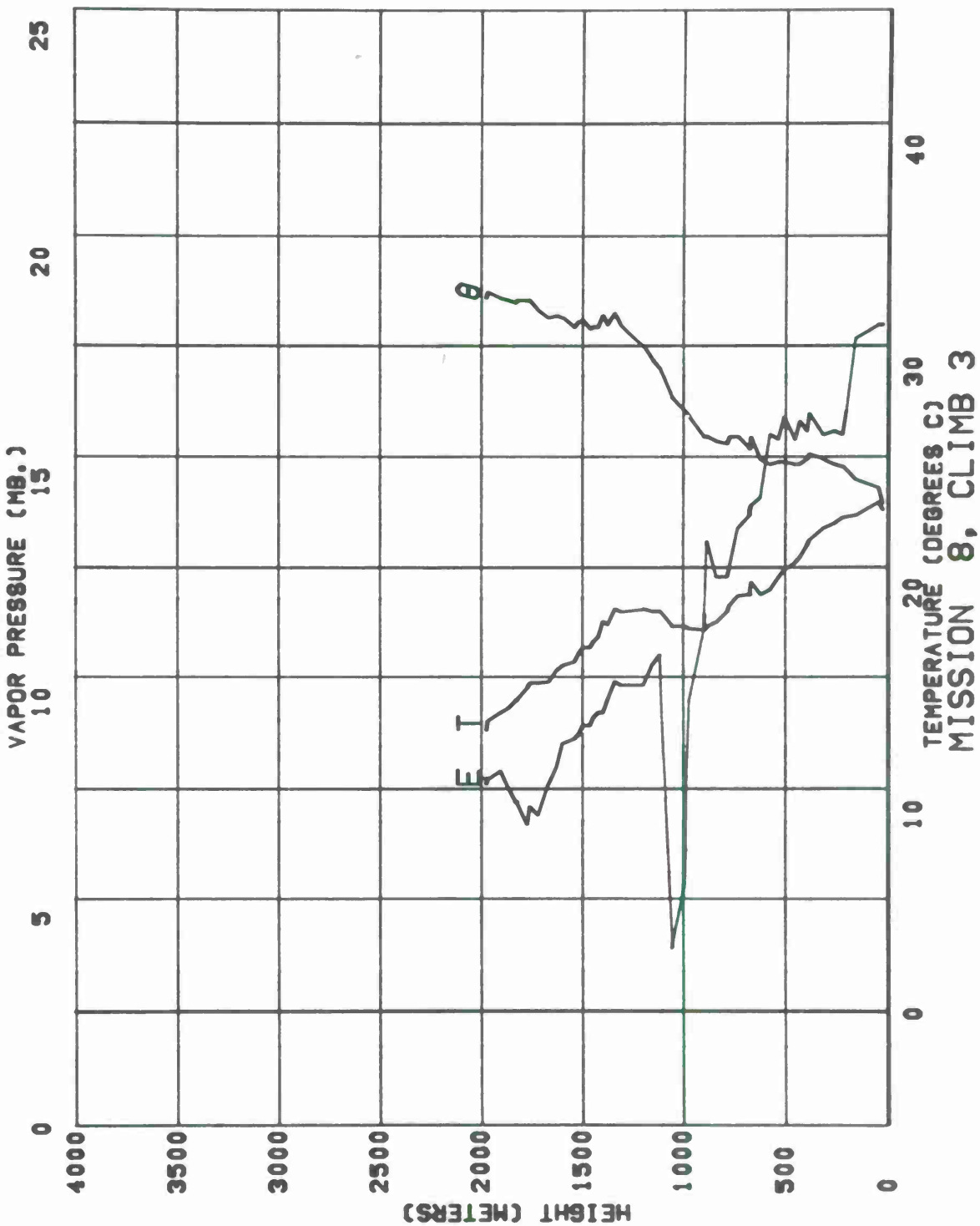
700
600
500
400
300
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
400
350
300
250
200
150
REFRACTIVITY (N UNITS)
M
N
MISSION 8, SPIRAL D


θ
T
VAPOR PRESSURE (MB.)
0
5
10
15
20
25
TEMPERATURE (DEGREES C)
-20
-10
0
10
20
30
40
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
E
MISSION 8, SPIRAL D



MISSION 8, CLIMB 3


MISSION 8, CLIMB 3
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
TEMPERATURE (DEGREES C)
-20
-10
0
10
20
30
40
VAPOR PRESSURE (MB.)
0
5
10
15
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25
θ
T
E

MISSION NO. 9

Date: 21 March 1969

Data were obtained on three spirals and one ascent on the triangular Flight Path I out of Key West.

Spiral	Location	Spiral Start Time Z	Local
A	a. Key West	1135	0635
B	b. 24-06 N, 81-51 W	1200	0700
Climb 1	b-c	1218	0718
C	c. 24-06 N, 81-08 W	1235	0735

SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300

STATUTE MILES

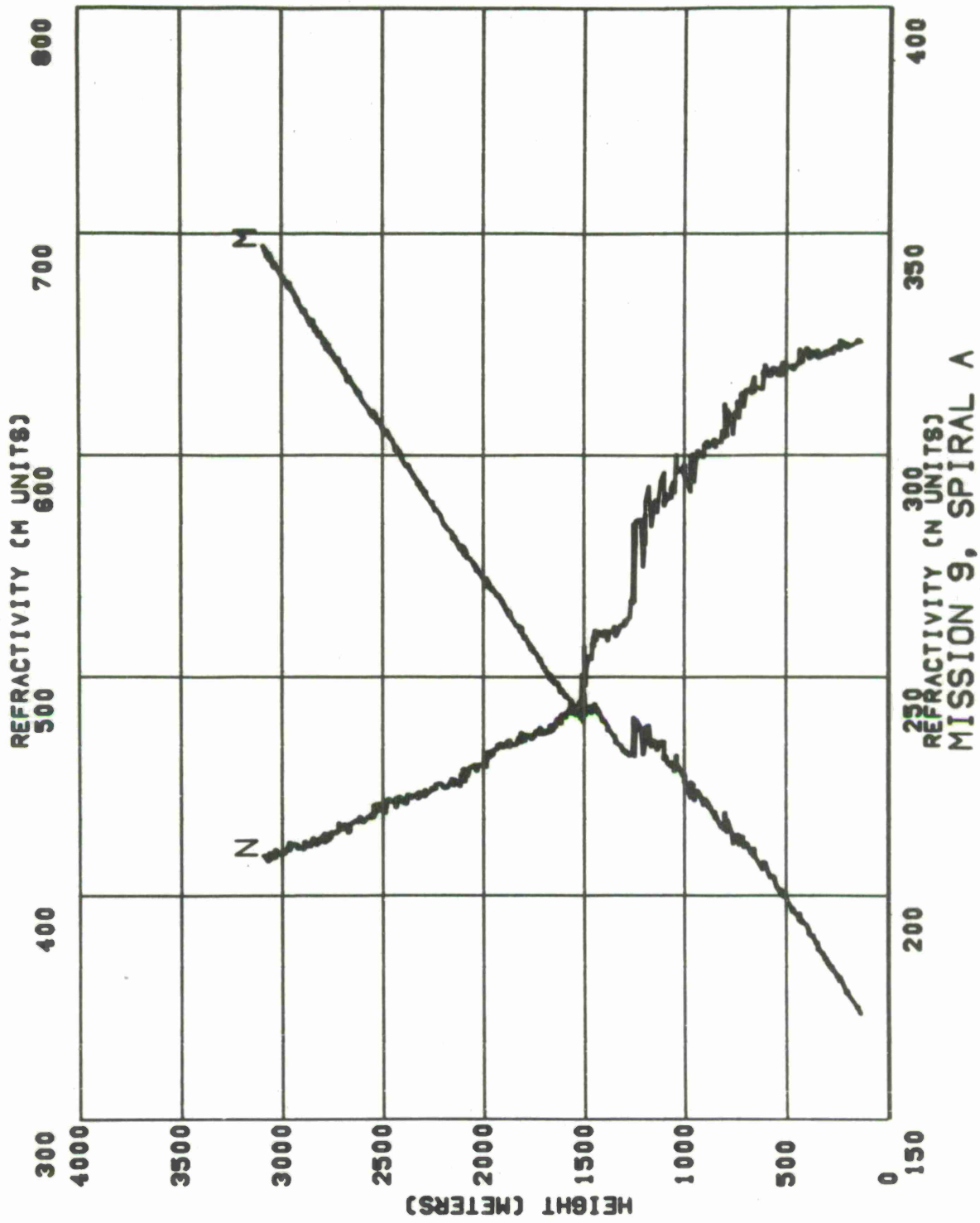
100 50 0 100 200 300 400

KILOMETERS

FLIGHT PATH I

MISSIONS 1 AND 2 — 6 MARCH 1969

MISSIONS 9, 10, AND 11 — 21 MARCH 1969


MISSION 9, SPIRAL A
REFRACTIVITY (M UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
M
N
300
400
500
600
700
800
250
300
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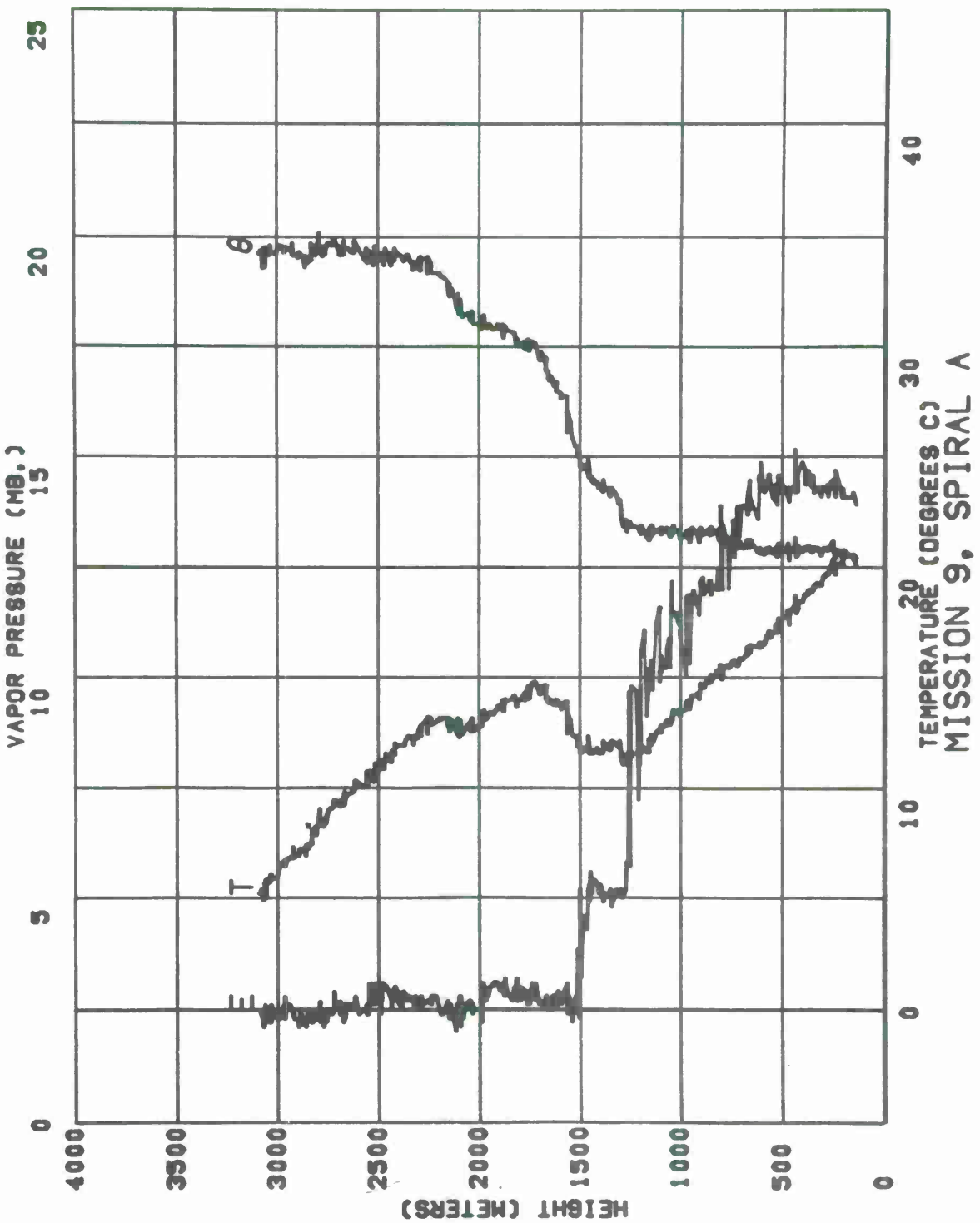
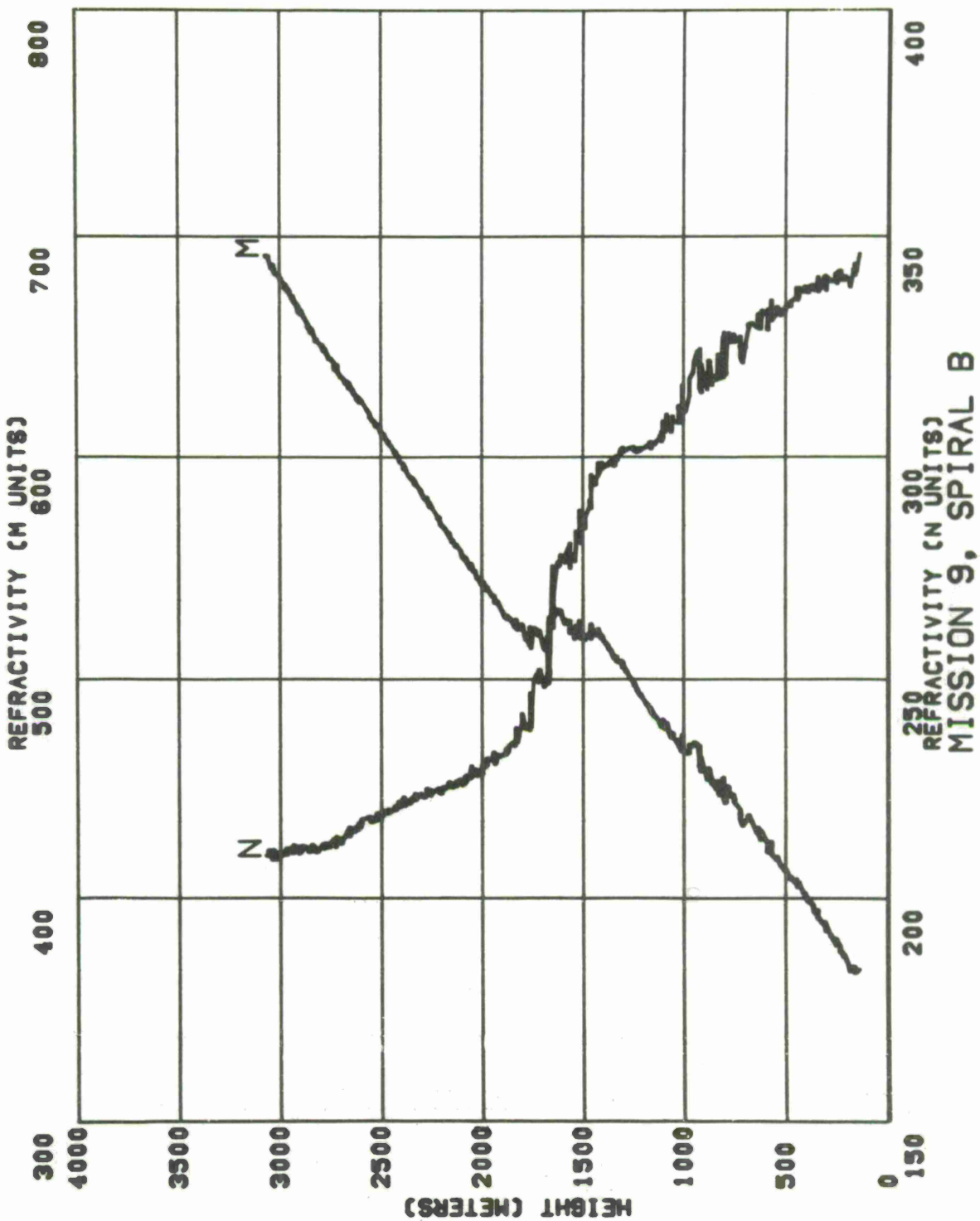
400
150
200
0
500
1000
1500
2000
2500
3000
3500
4000


MISSION 9, SPIRAL A
VAPOR PRESSURE (MB.)
TEMPERATURE (DEGREES C)
HEIGHT (METERS)
θ
T
0
5
10
15
20
25
0
10
20
30
40
4000
3500
3000
2500
2000
1500
1000
500
0


REFRACTIVITY (M UNITS)
300
400
500
600
700
800
HEIGHT (METERS)
4000
3500
3000
2500
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1500
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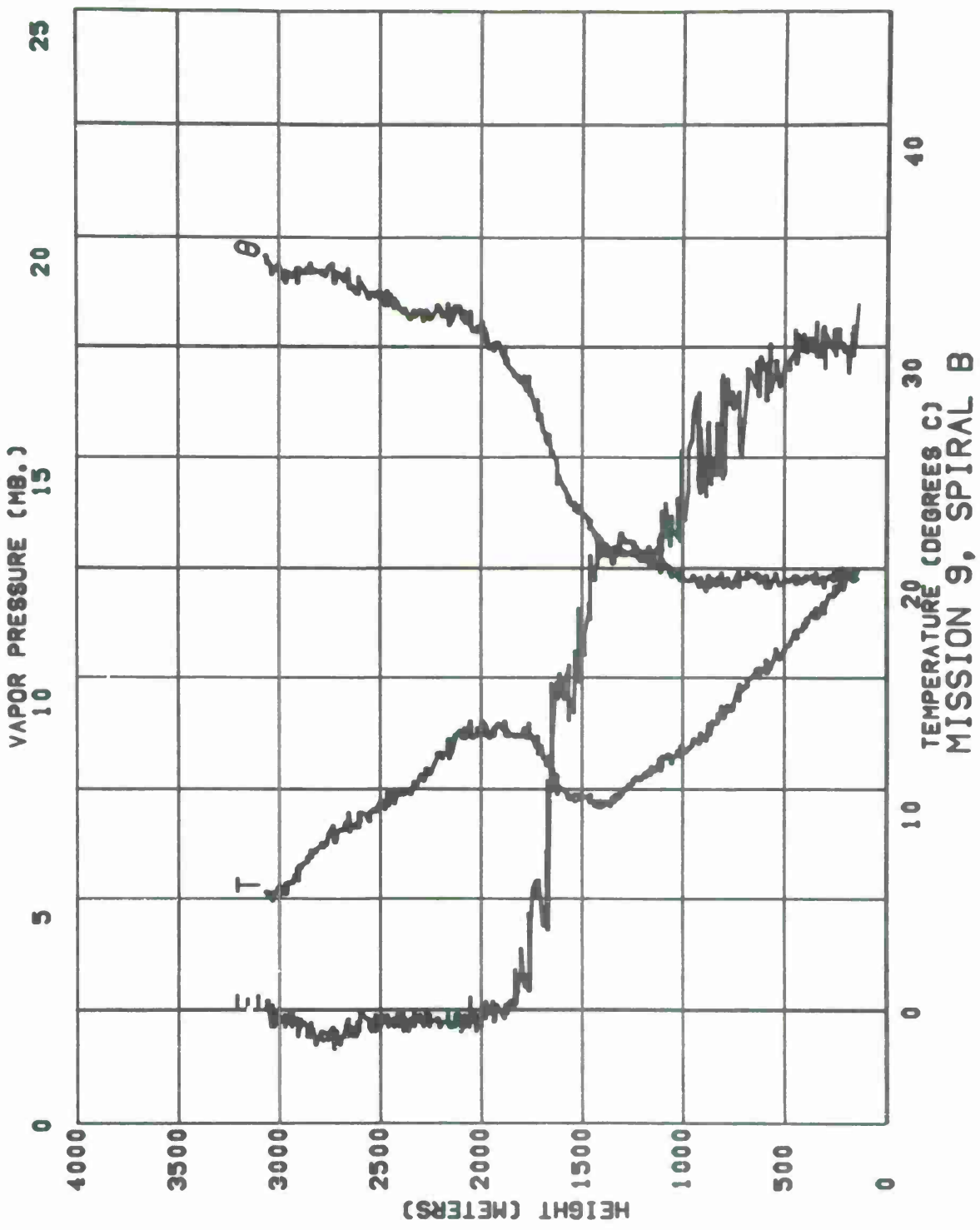
500
0
REFRACTIVITY (N UNITS)
150
200
250
300
350
400
M
N
MISSION 9, SPIRAL B


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
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500
0
TEMPERATURE (DEGREES C)
0
10
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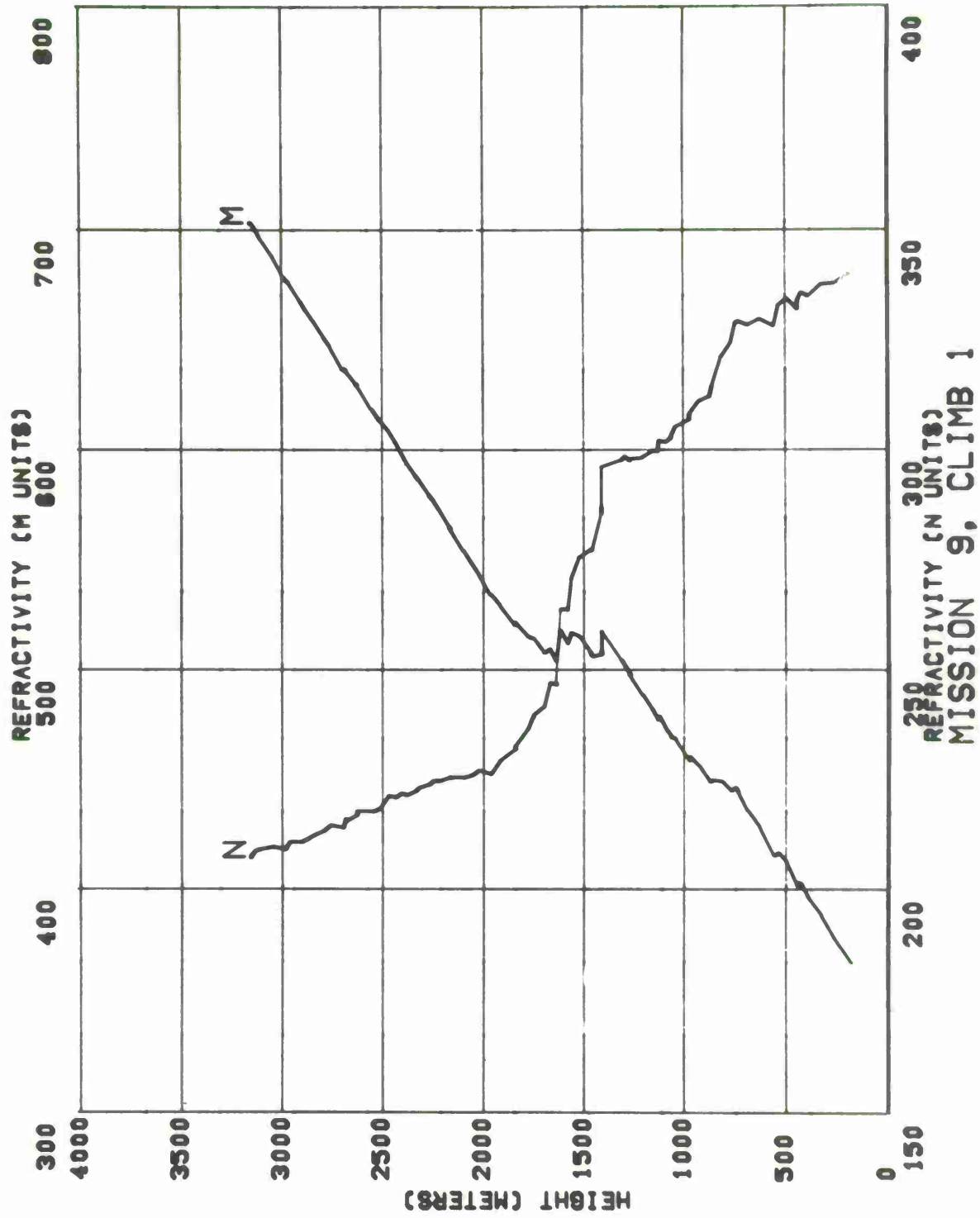
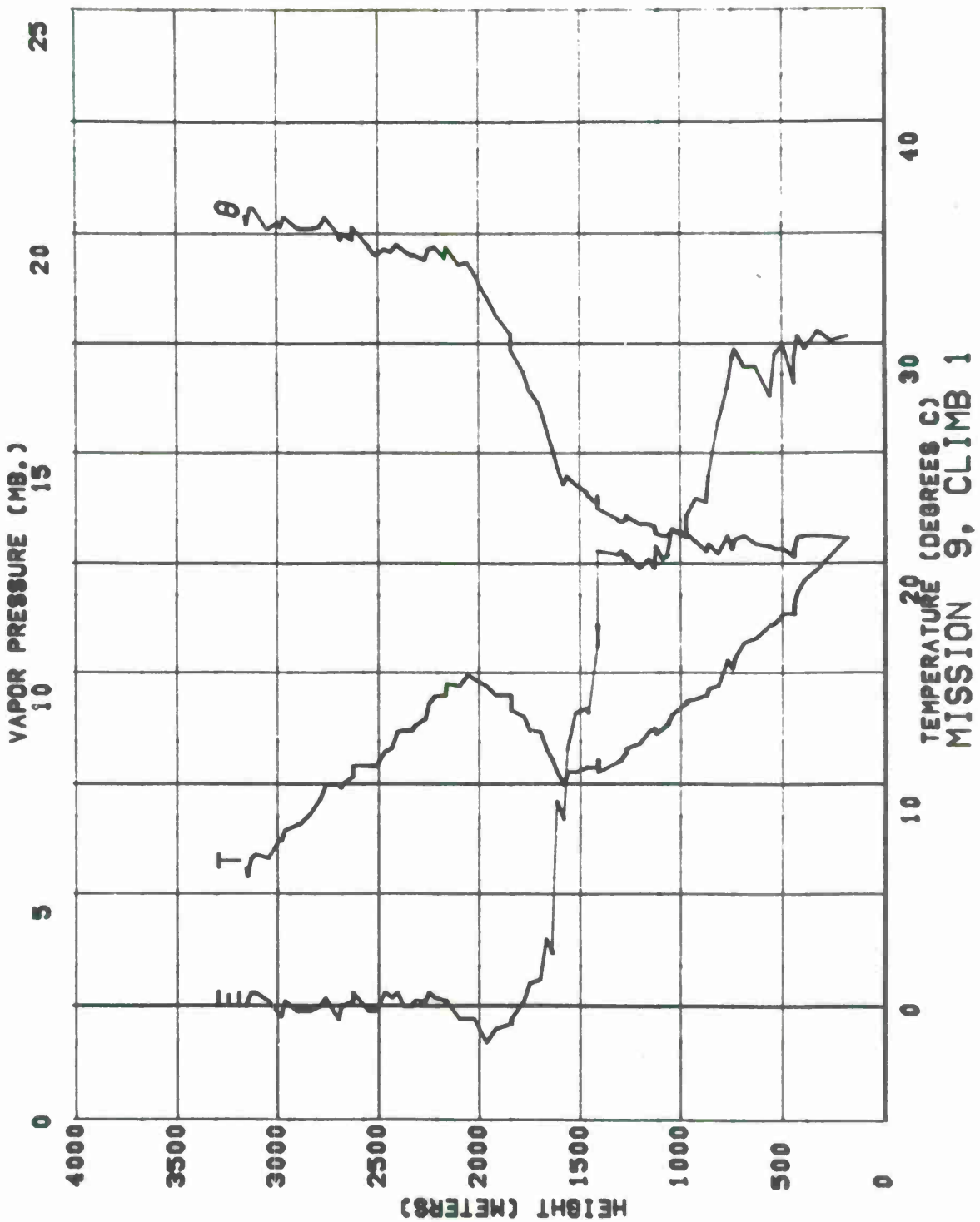
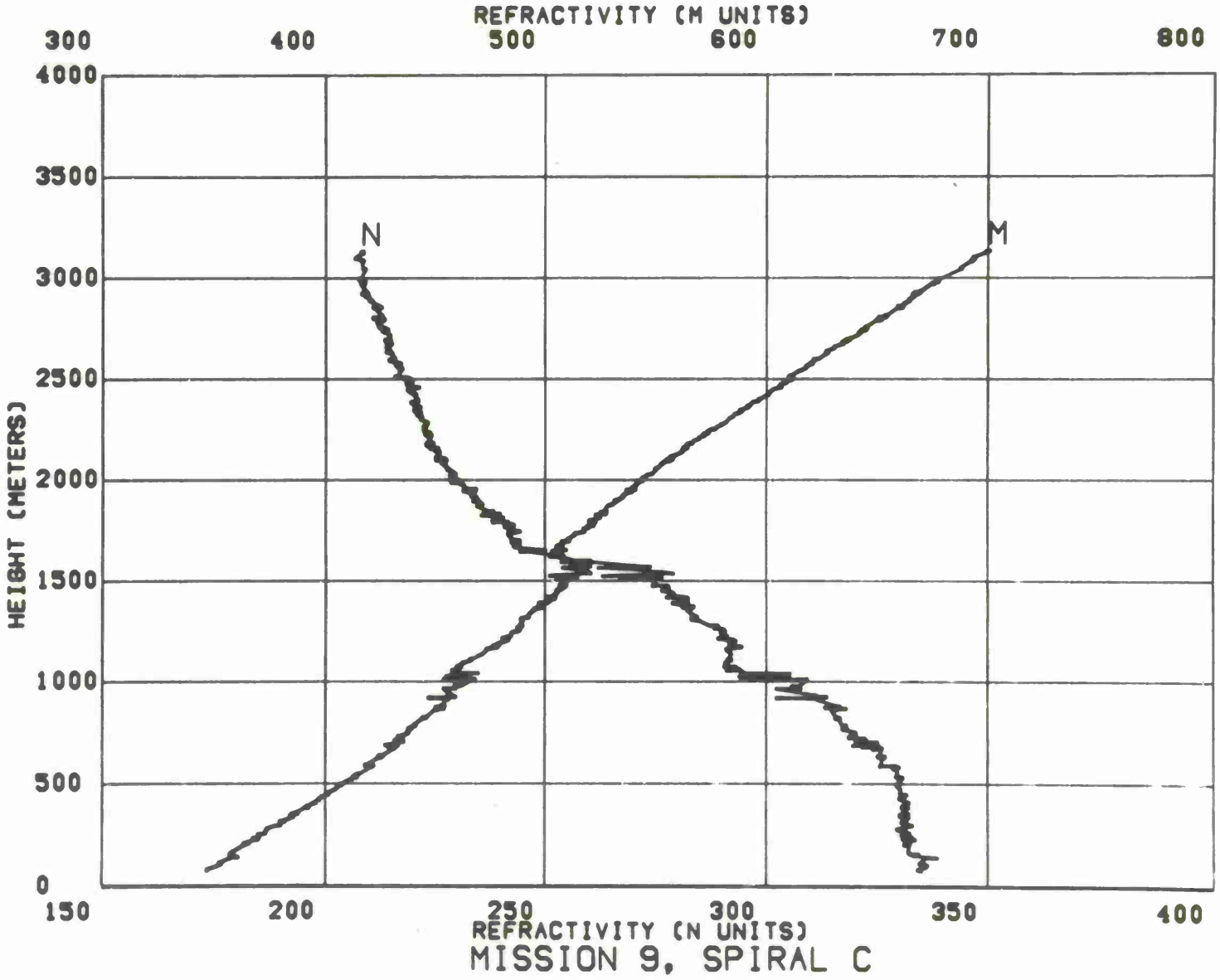
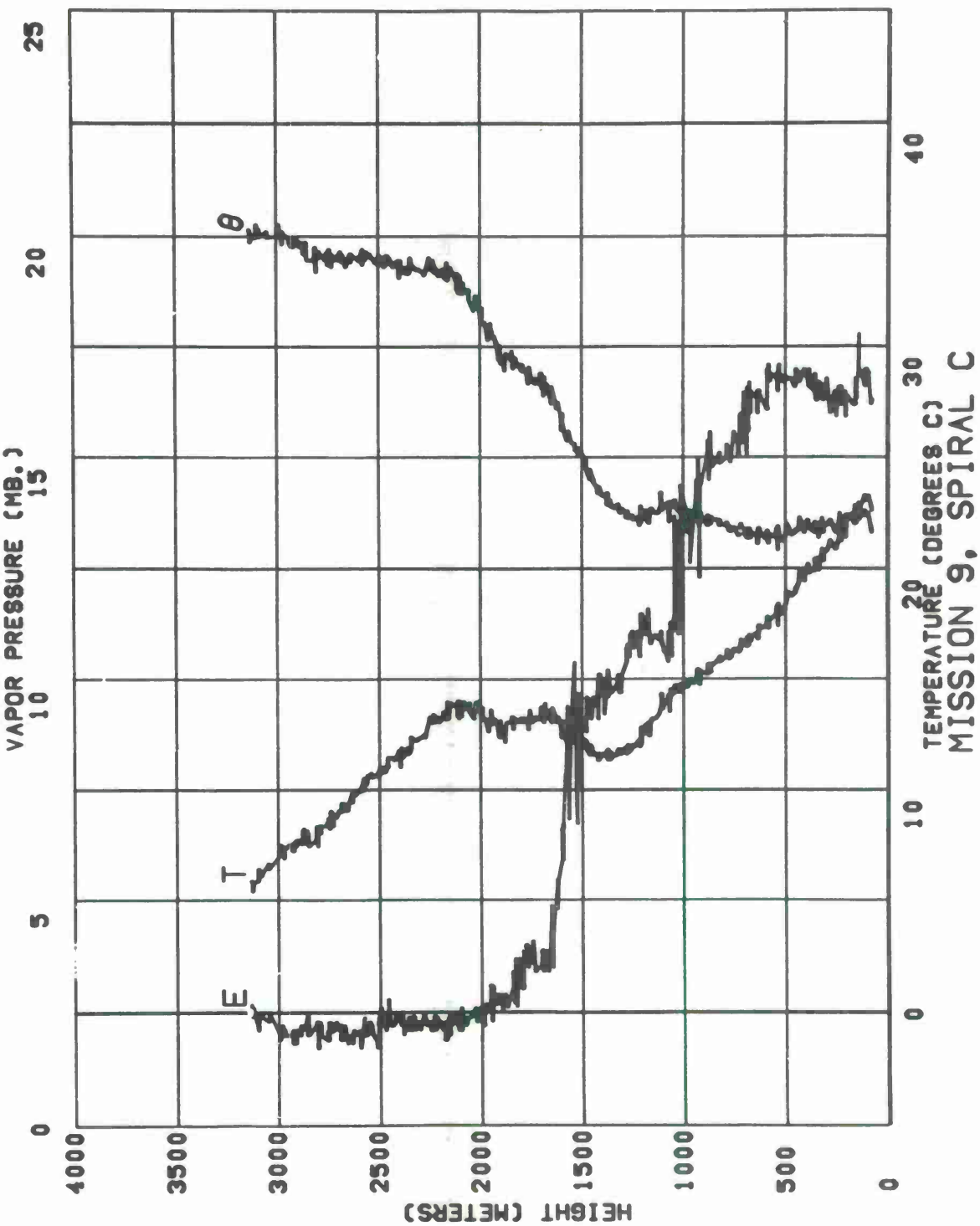
T
MISSION 9, SPIRAL B


MISSION 9, CLIMB 1
REFRACTIVITY (N UNITS)
REFRACTIVITY (M UNITS)
HEIGHT (METERS)
M
N
300
400
500
600
700
800
150
200
250
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
TEMPERATURE (DEGREES C)
0
10
20
30
40
θ
T
MISSION 9, CLIMB 1



MISSION 9, SPIRAL C


MISSION 9, SPIRAL C
TEMPERATURE (DEGREES C)
VAPOR PRESSURE (MB.)
HEIGHT (METERS)
θ
T
E
0
5
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15
20
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-20
-10
0
10
20
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4000
3500
3000
2500
2000
1500
1000
500
0

MISSION NO. 10

Date: 21 March 1969

Data were obtained on three spirals and one ascent along Flight Path I.

Spiral	Location	Spiral Start Time Z	Local
A	b. 24-06 N, 81-51 W	1608	1108
Climb 1	b-c	1626	1126
B	c. 24-06 N, 81-08 W	1645	1145
Climb 2			
C	a. Key West	1720	1220

B6831

SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300

STATUTE MILES

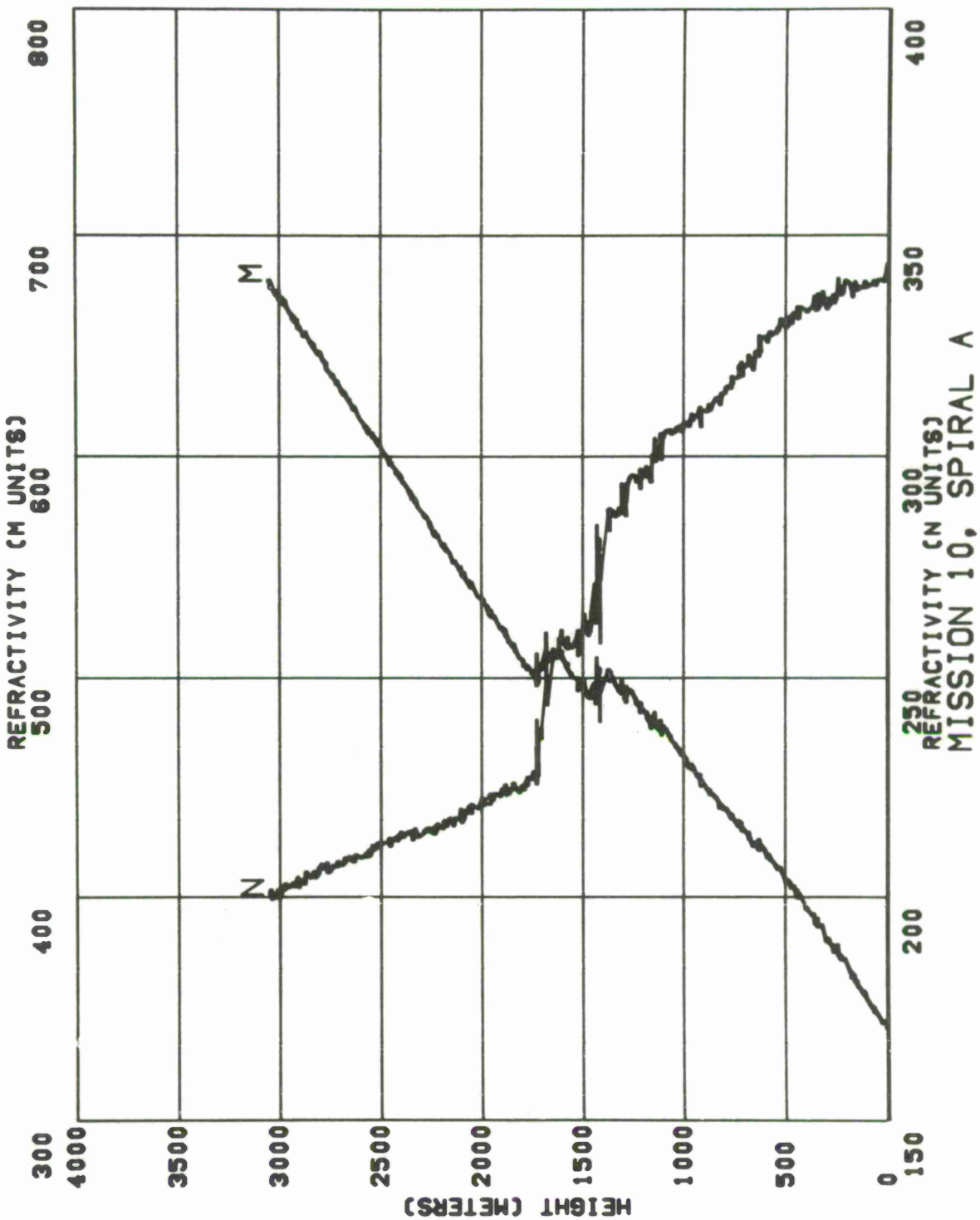
100 50 0 100 200 300 400

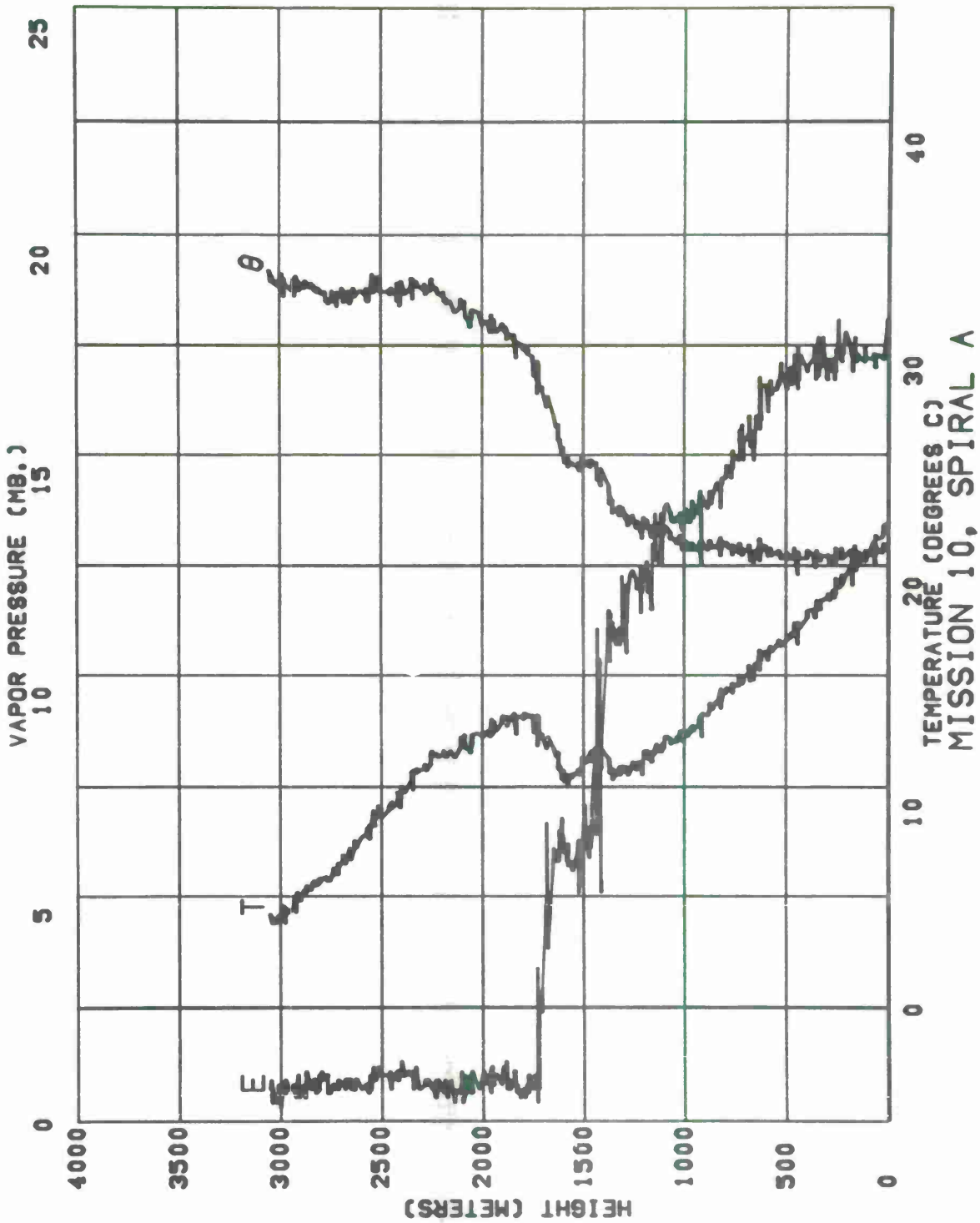
KILOMETERS

FLIGHT PATH I

MISSIONS 1 AND 2 — 6 MARCH 1969

MISSIONS 9, 10, AND 11 — 21 MARCH 1969


REFRACTIVITY (M UNITS)
300
400
500
600
700
800
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
M
N
REFRACTIVITY (N UNITS)
150
200
250
300
350
400
MISSION 10, SPIRAL A


MISSION 10, SPIRAL A
VAPOR PRESSURE (MB.)
TEMPERATURE (DEGREES C)
HEIGHT (METERS)
θ
T
E
0
5
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15
20
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0
10
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30
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4000
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3000
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1000
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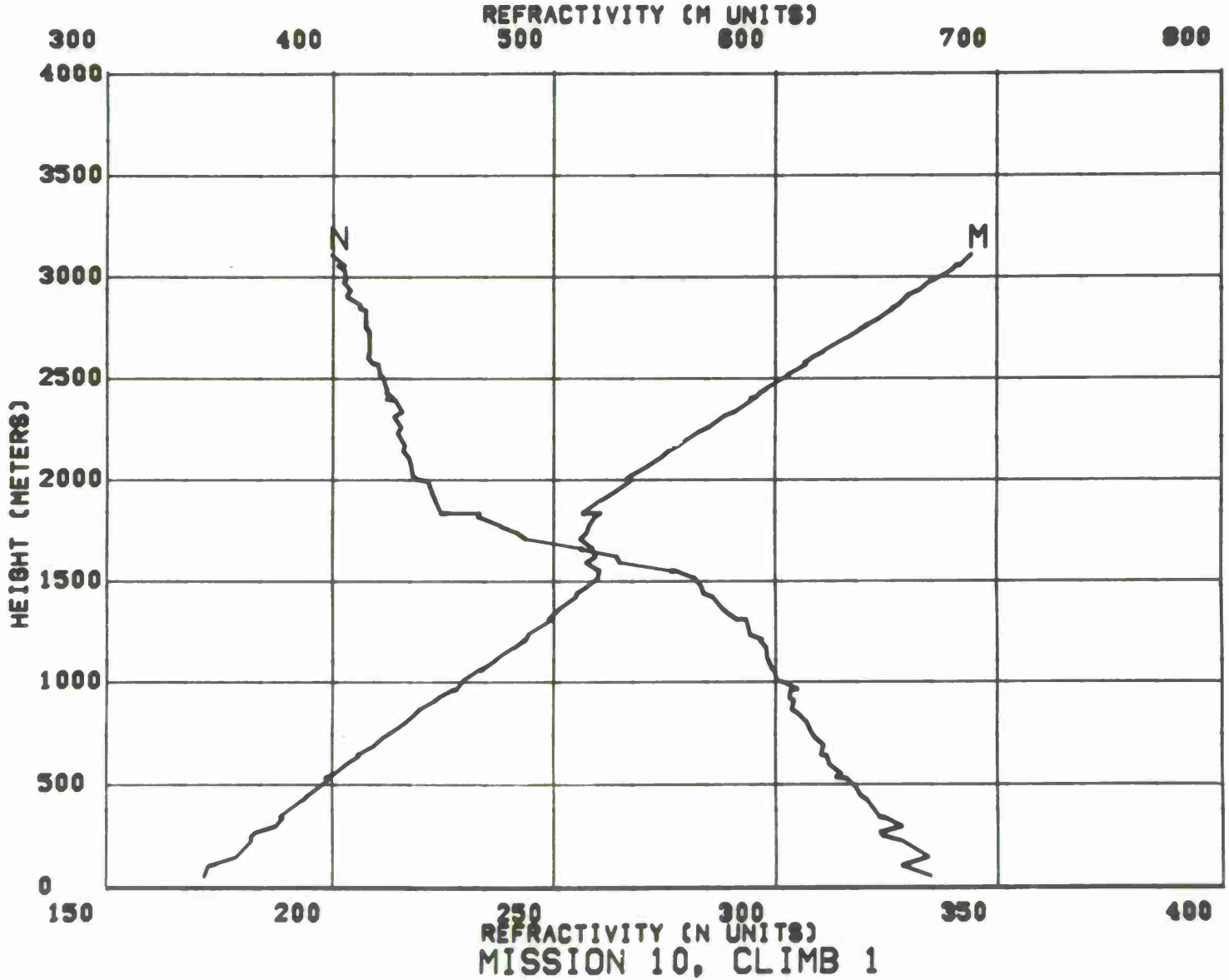
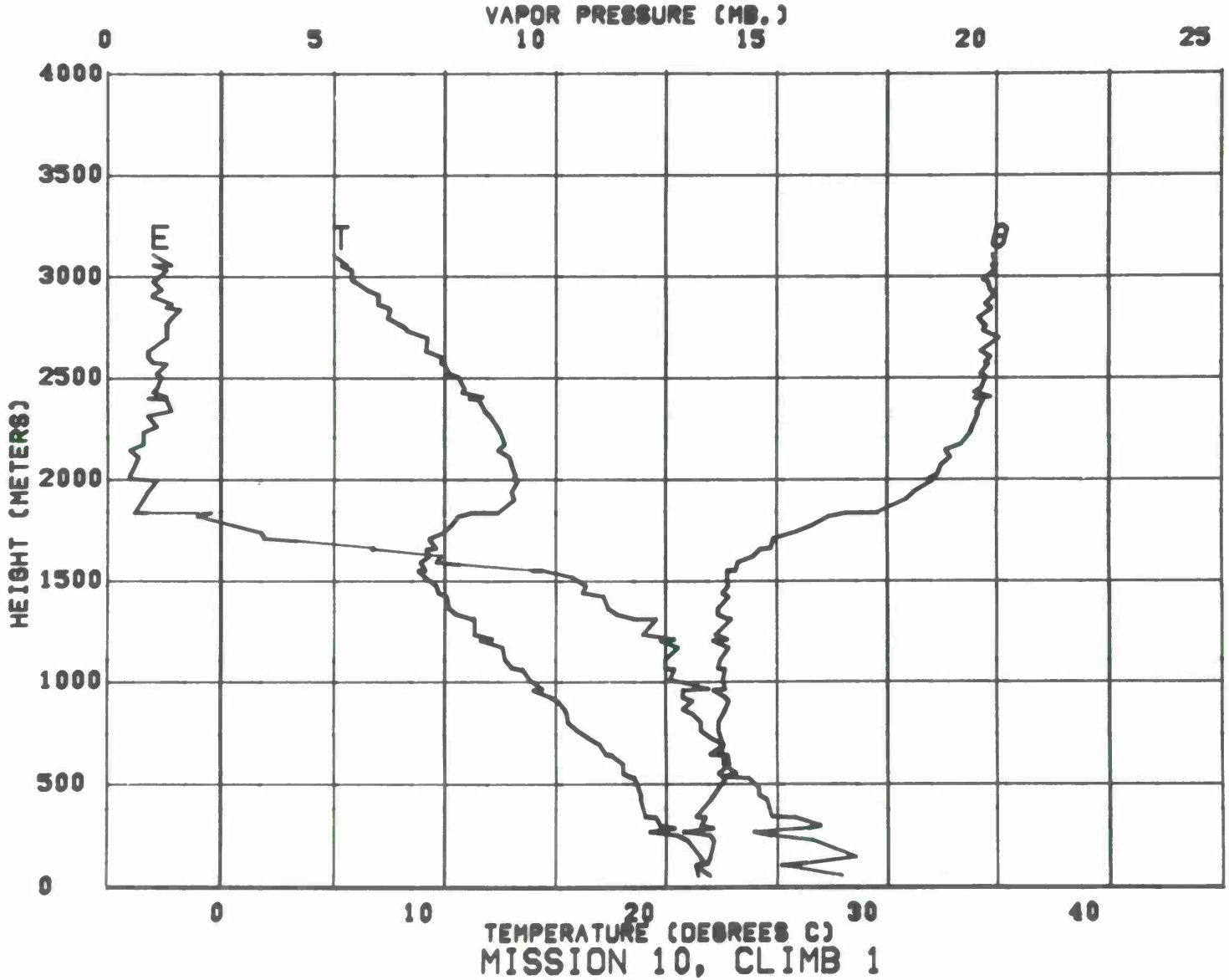
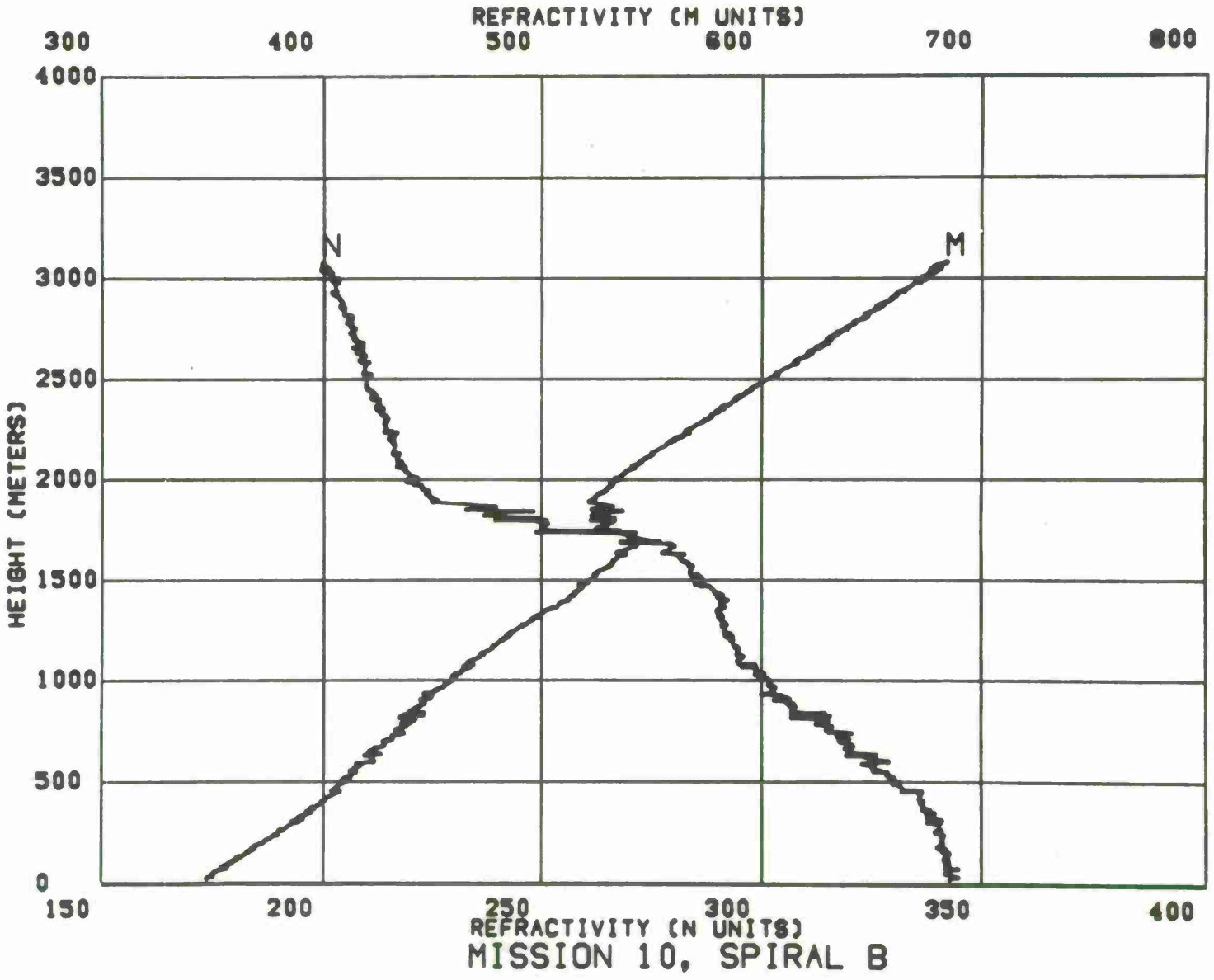
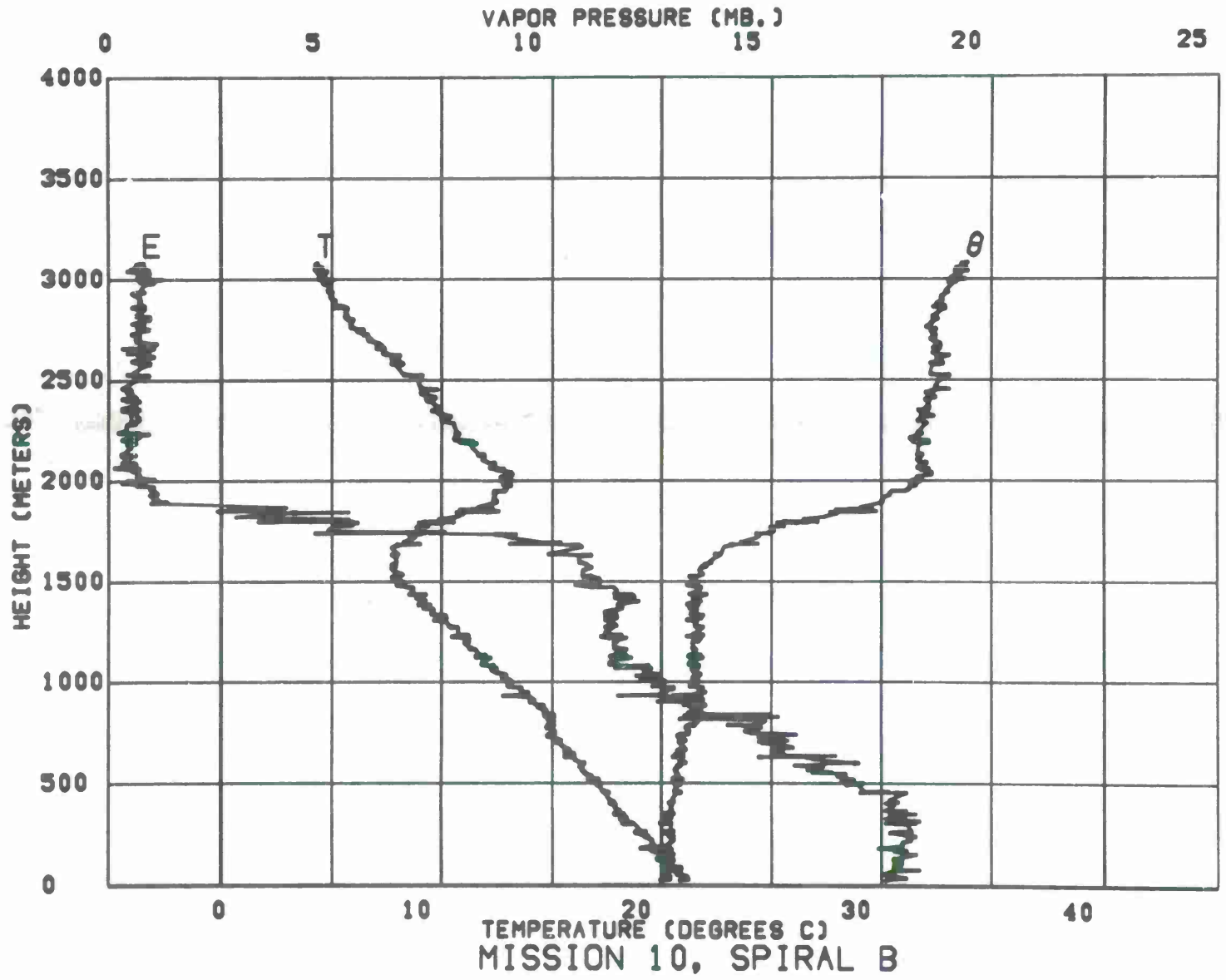
0


REFRACTIVITY (M UNITS)
300
400
500
600
700
800
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
N
M
150
200
250
300
350
400
REFRACTIVITY (N UNITS)
MISSION 10, CLIMB 1

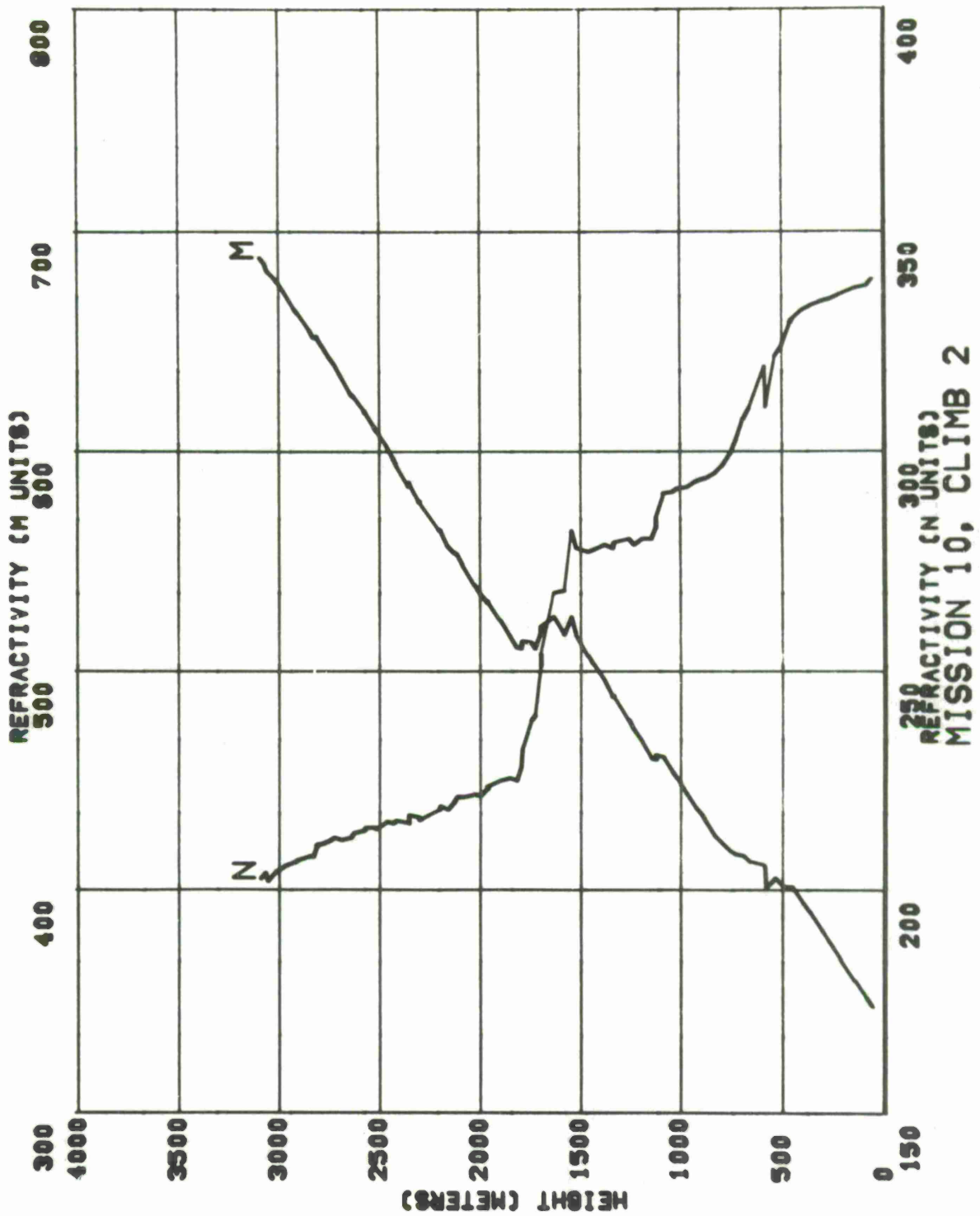

VAPOR PRESSURE (MB.)
0
5
10
15
20
25
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
E
T
B
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 10, CLIMB 1

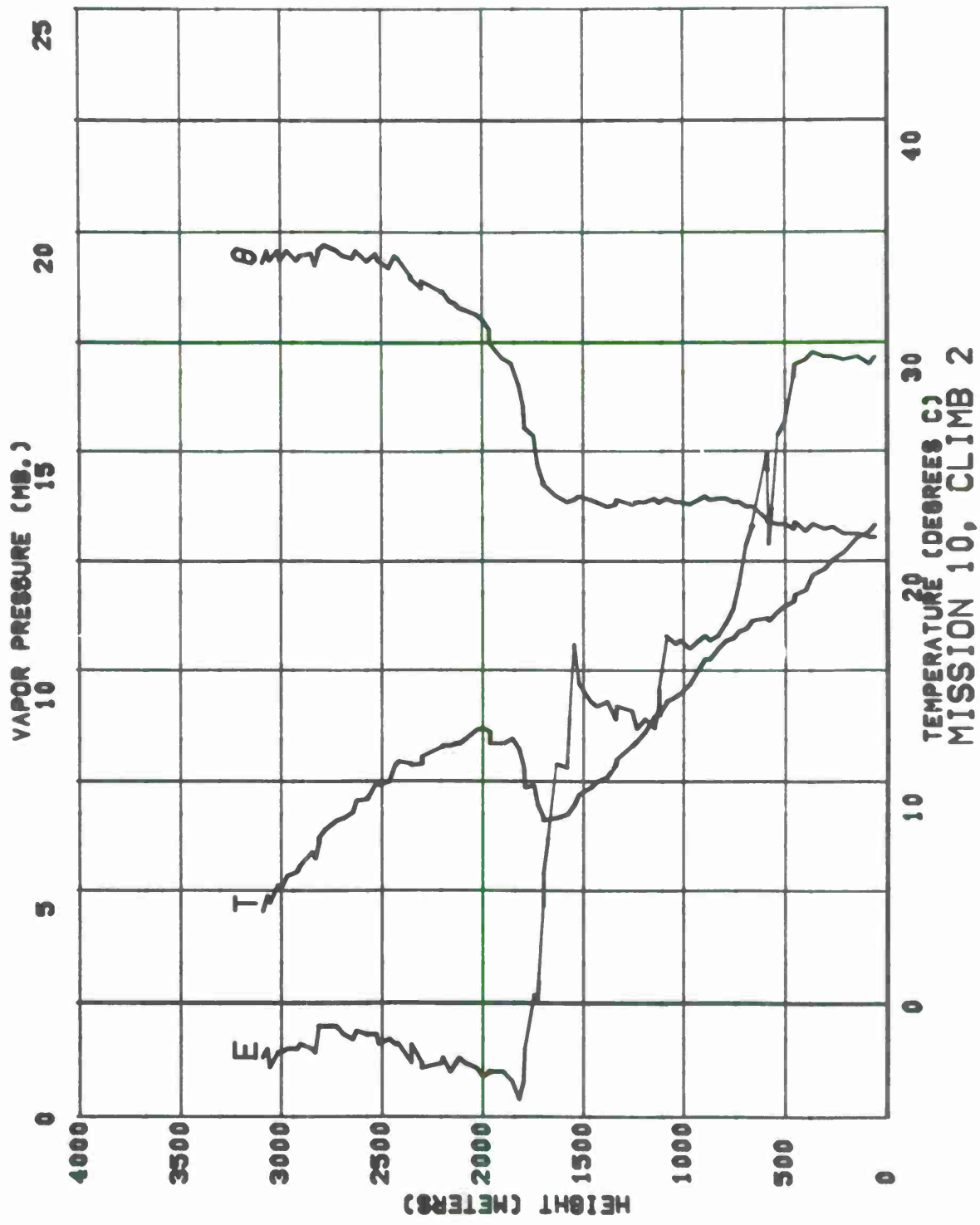


MISSION 10, SPIRAL B



MISSION 10, SPIRAL B


REFRACTIVITY (M UNITS)
300
400
500
600
700
800
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
M
N
REFRACTIVITY (N UNITS)
150
200
250
300
350
400
MISSION 10, CLIMB 2


MISSION 10, CLIMB 2
TEMPERATURE (DEGREES C)
VAPOR PRESSURE (MB.)
HEIGHT (METERS)
θ
T
E
0
5
10
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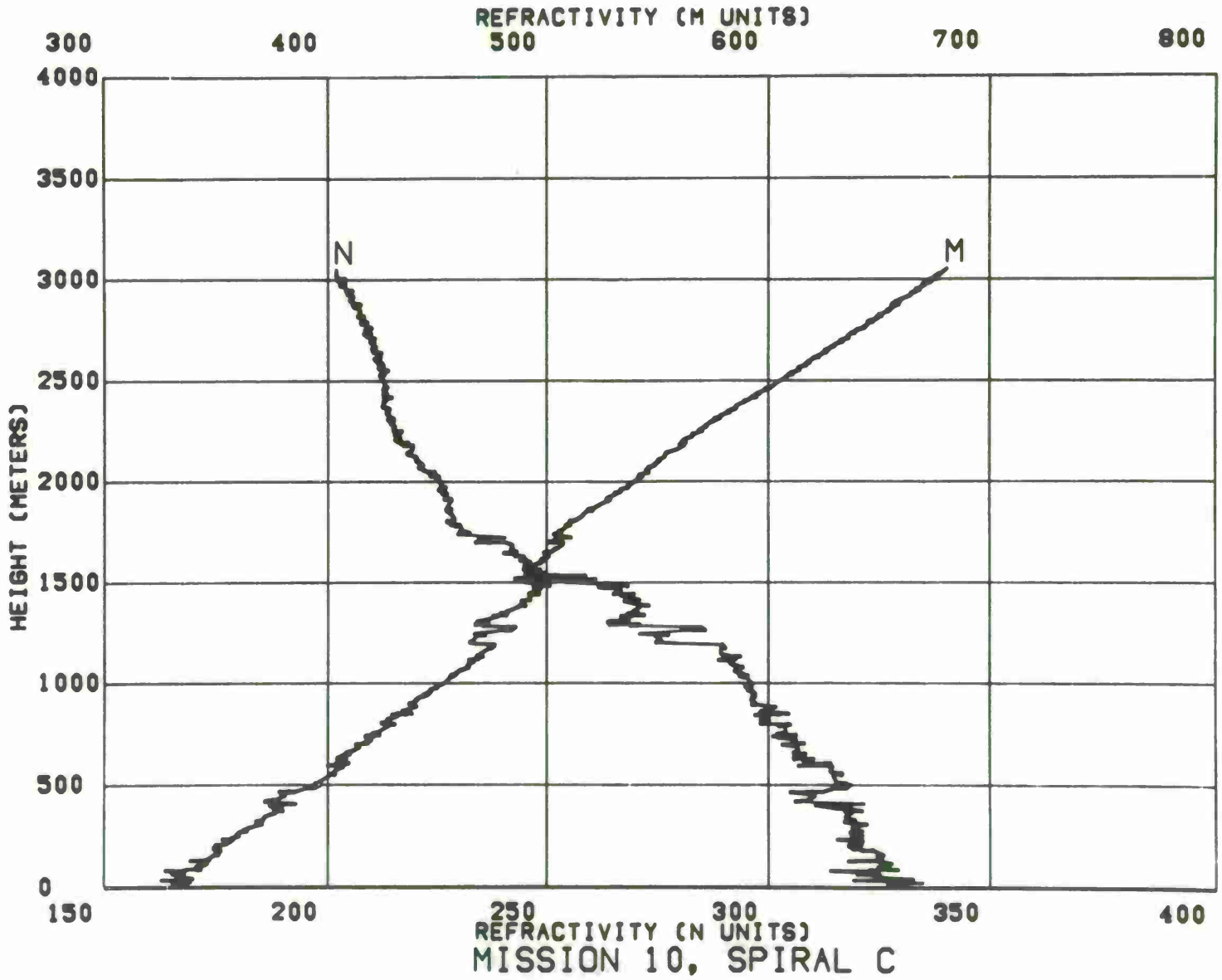
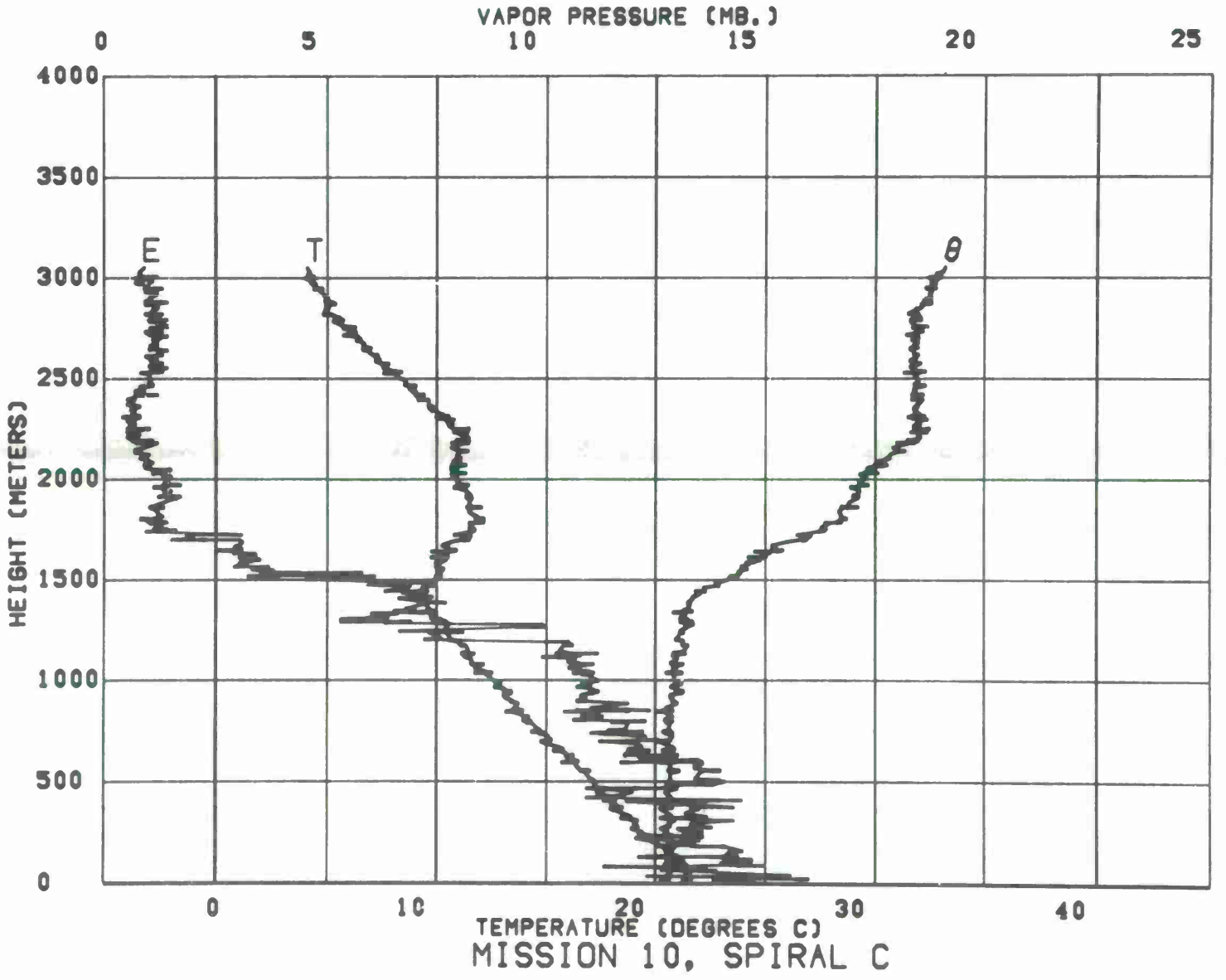
4000
3500
3000
2500
2000
1500
1000
500
0



MISSION 10, SPIRAL C



MISSION 10, SPIRAL C

MISSION NO. 11

Date: 21 March 1969

Data were obtained on three spirals and one ascent along Flight Path I.

Spiral	Location	Spiral Start Time Z	Local
A	b. 24-06 N, 81-51 W	2159	1659
Climb 1	b-c	2216	1716
B	c. 24-06 N, 81-08 W	2233	1733
C	a. Key West	2318	1818

SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300

STATUTE MILES

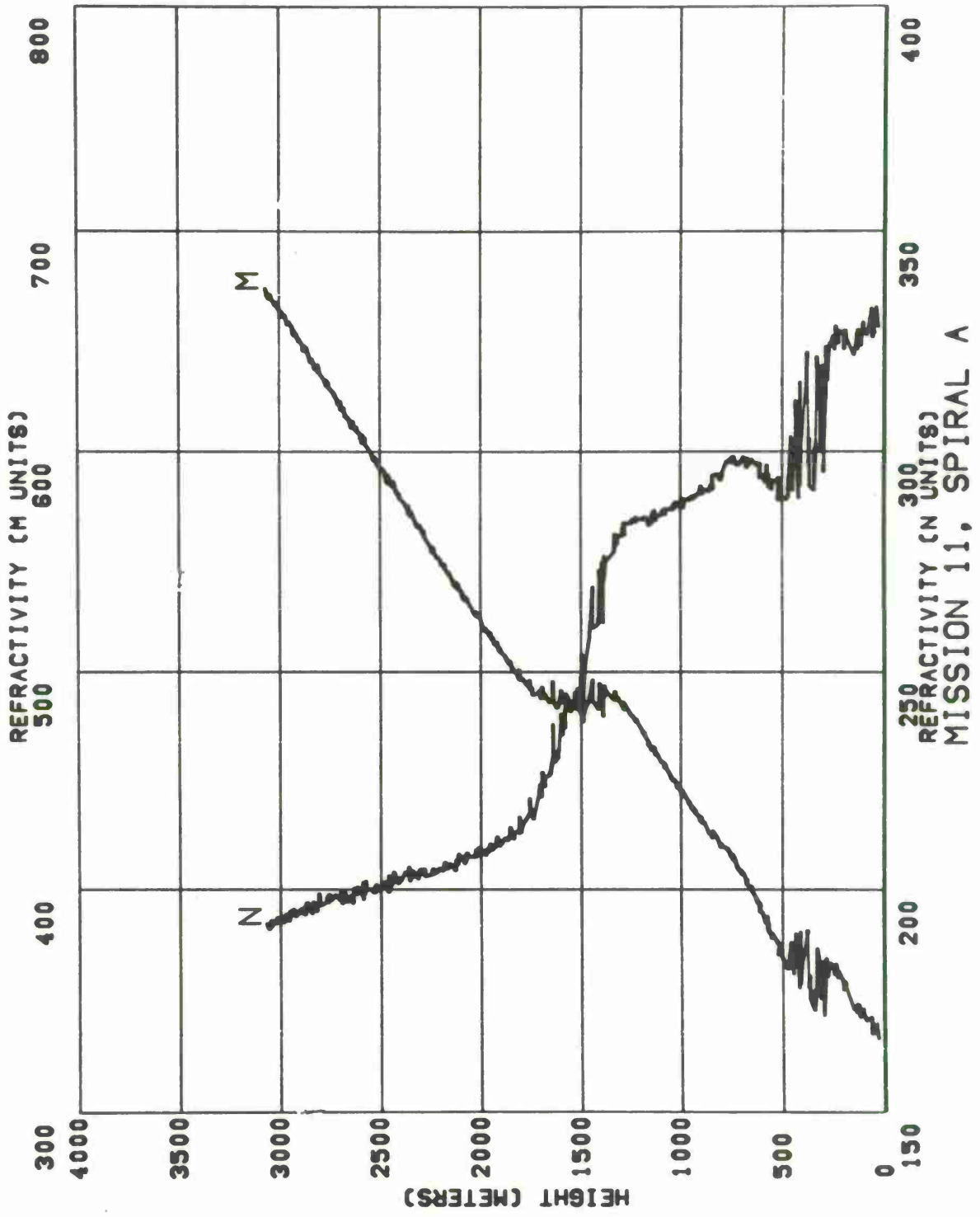
100 50 0 100 200 300 400

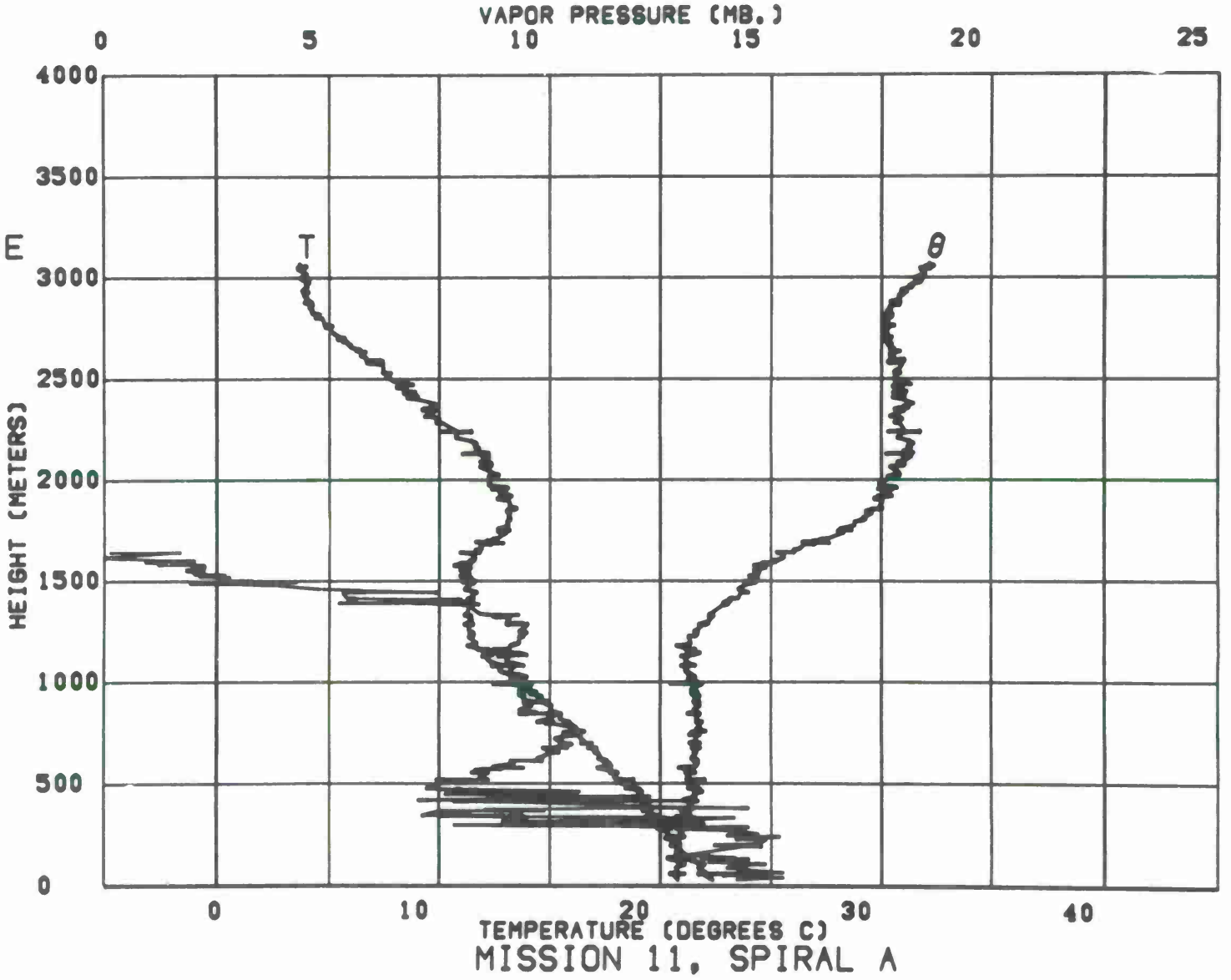
KILOMETERS

FLIGHT PATH I

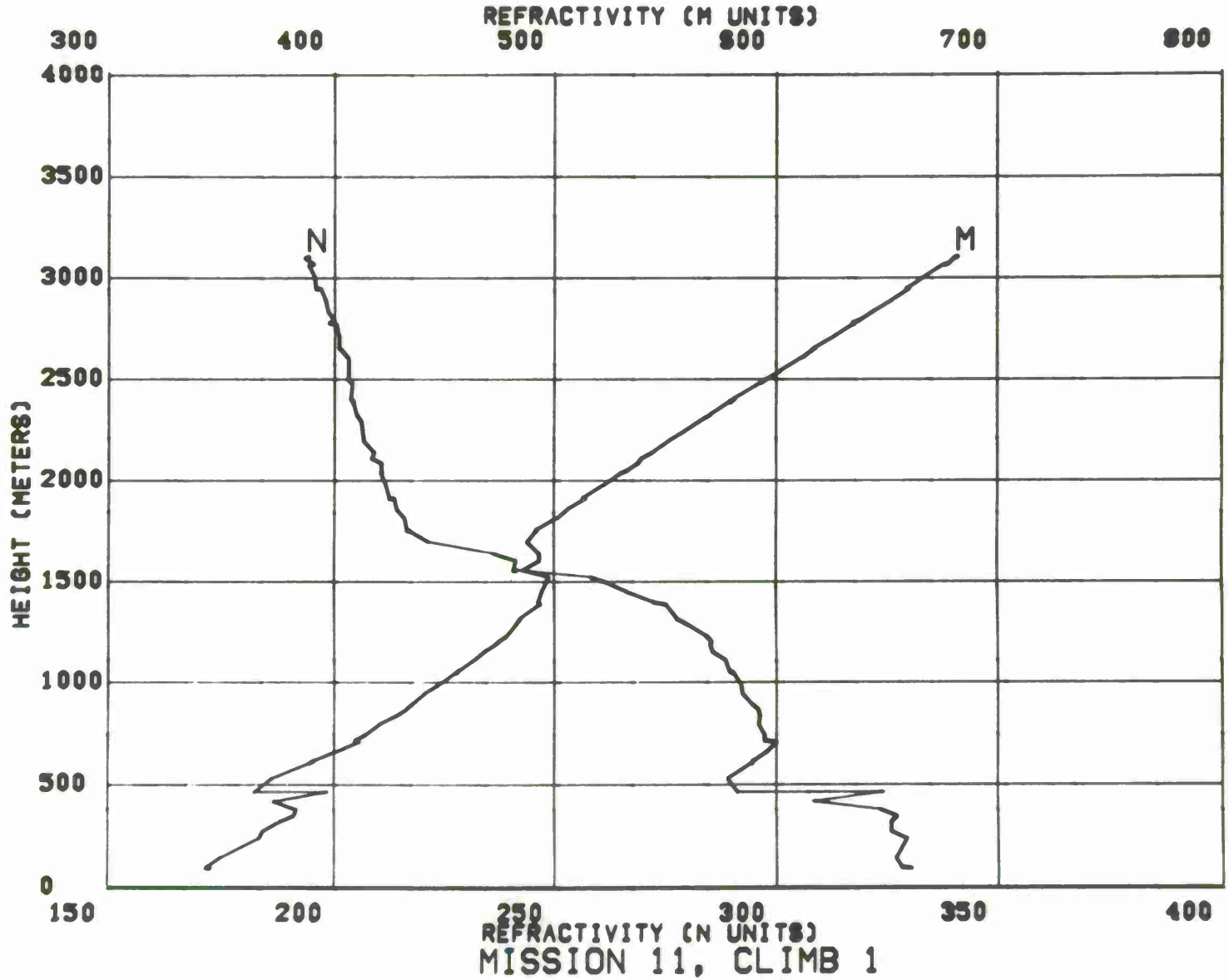
MISSIONS 1 AND 2 — 6 MARCH 1969

MISSIONS 9, 10, AND 11 — 21 MARCH 1969

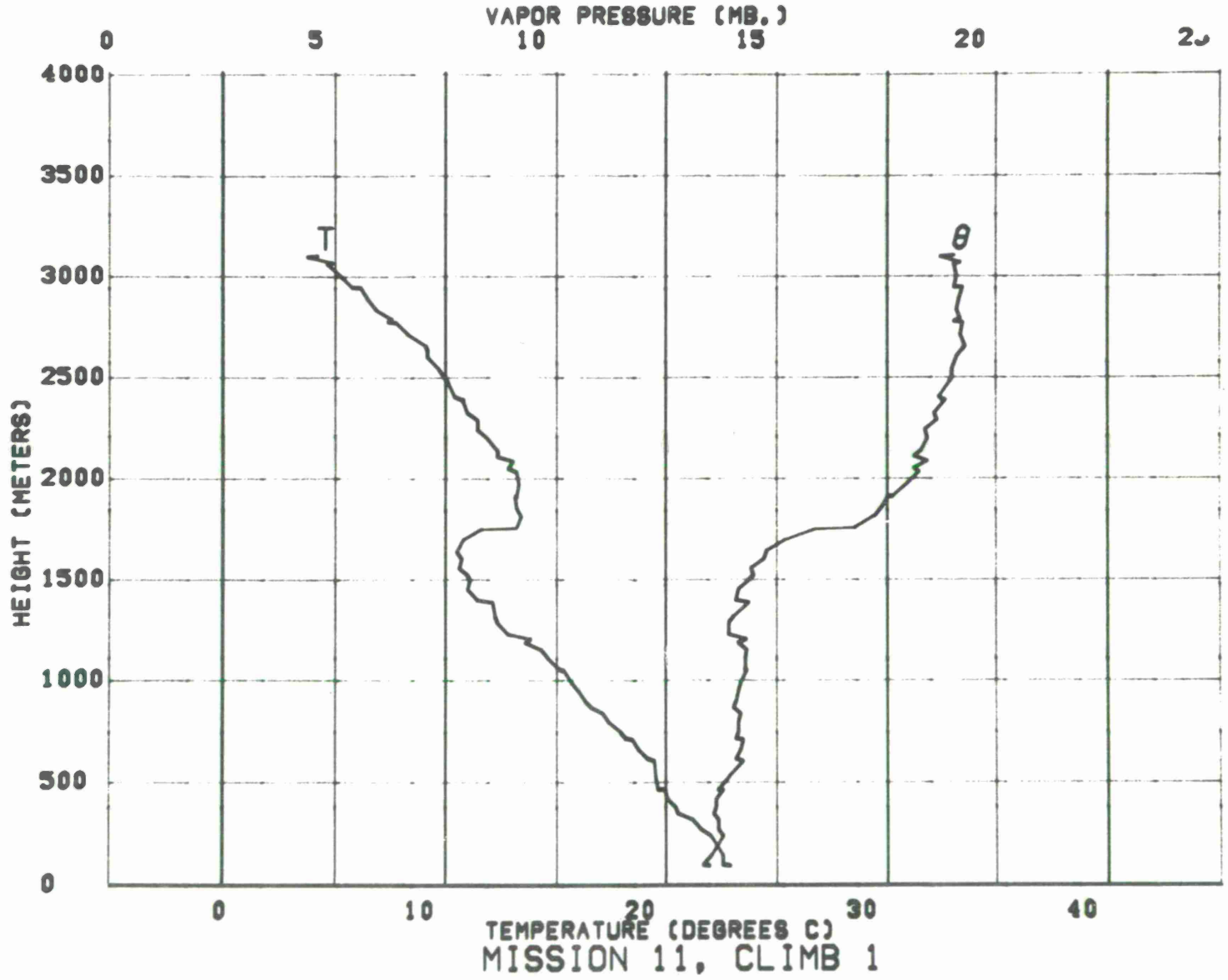

REFRACTIVITY (M UNITS)
800
700
600
500
400
300
REFRACTIVITY (N UNITS)
400
350
300
250
200
150
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
M
N
MISSION 11, SPIRAL A



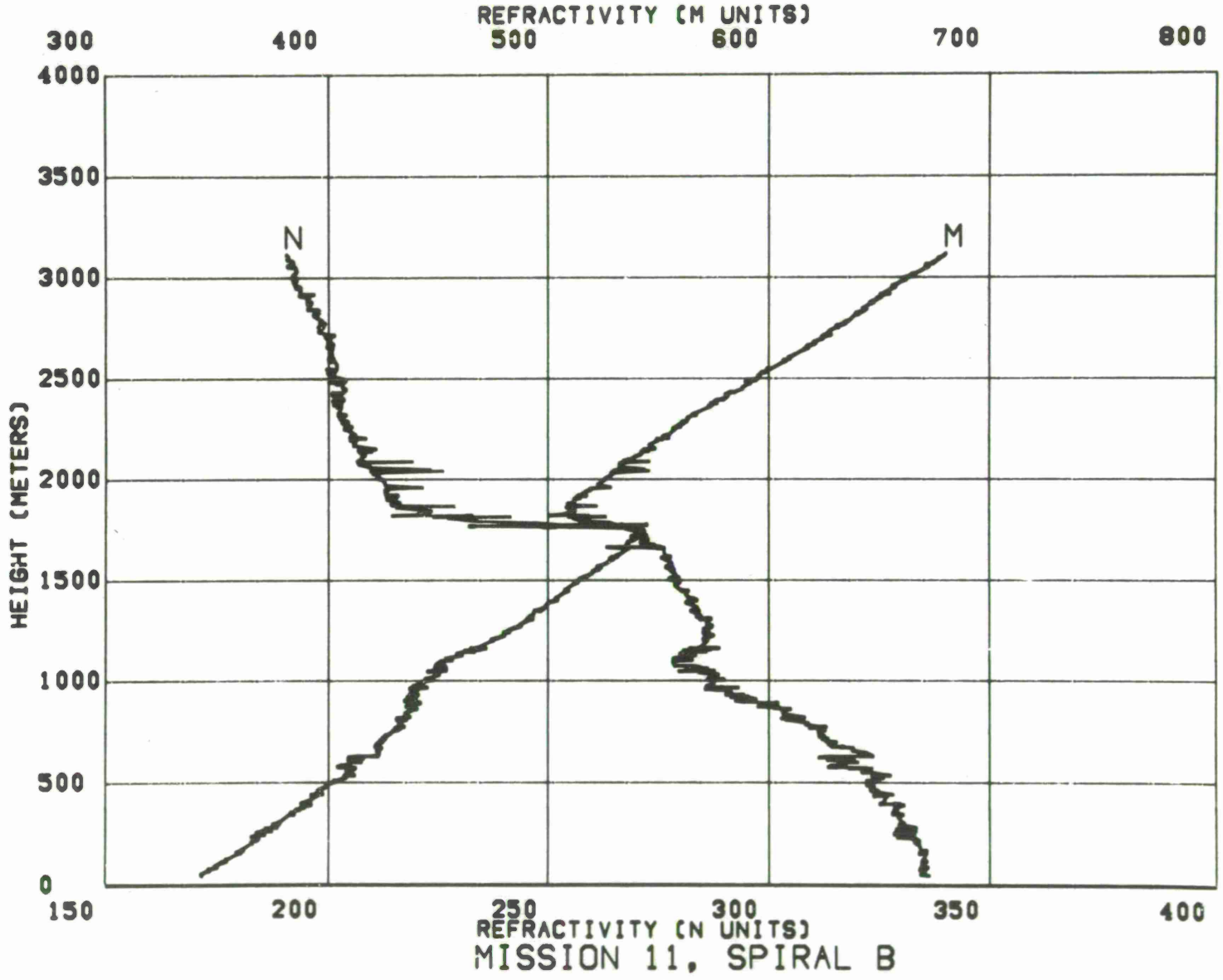
MISSION 11, SPIRAL A



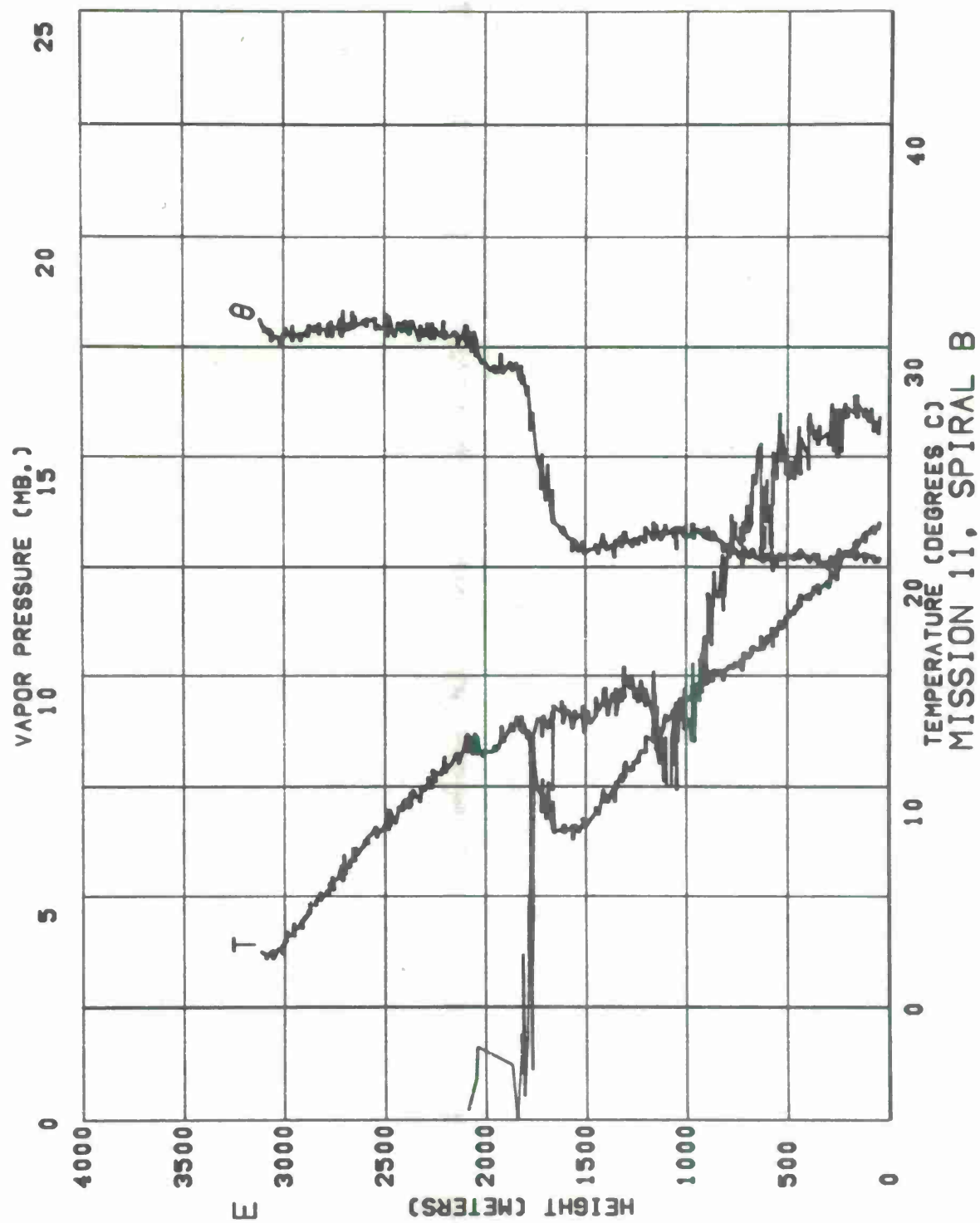
MISSION 11, CLIMB 1

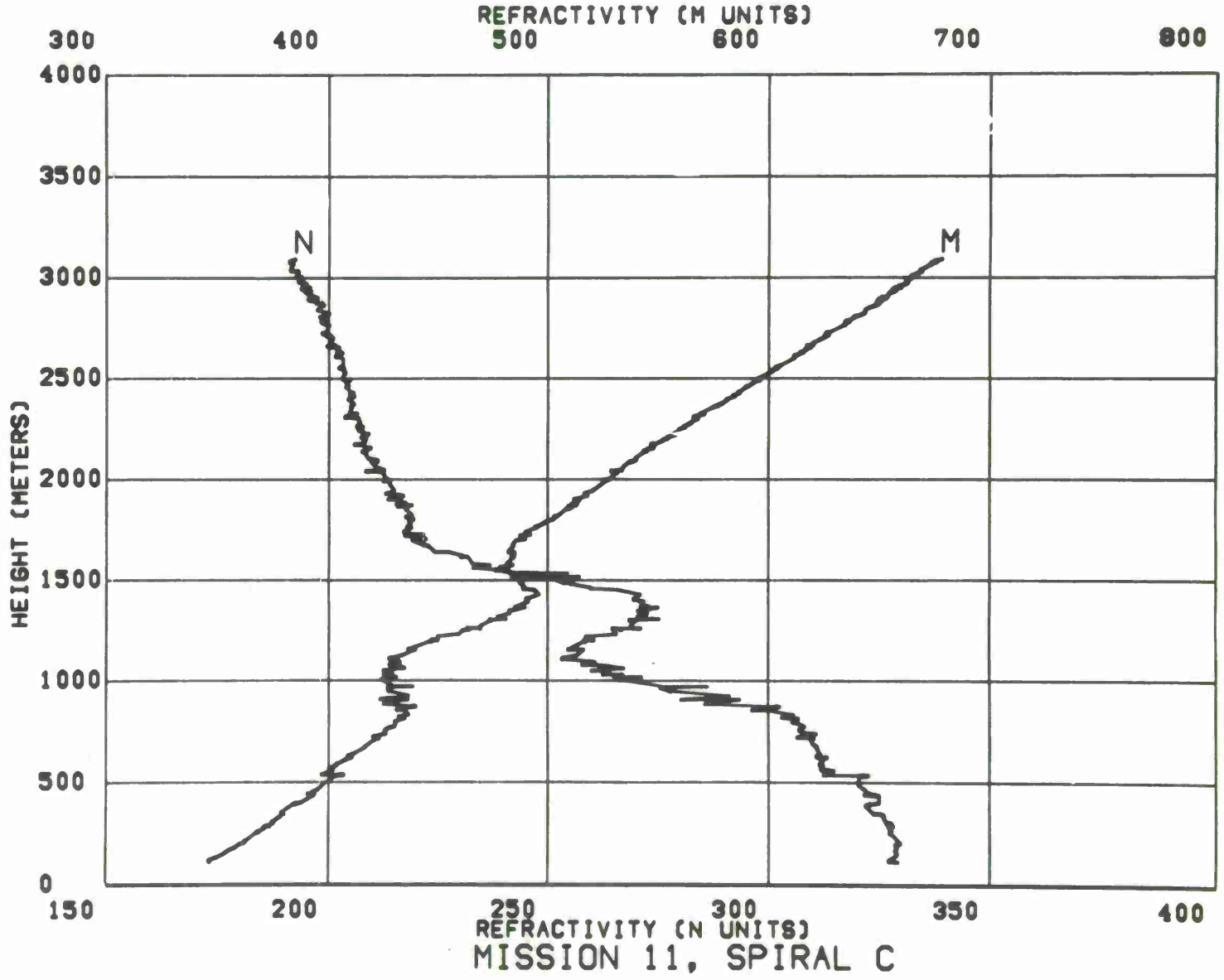


MISSION 11, CLIMB 1

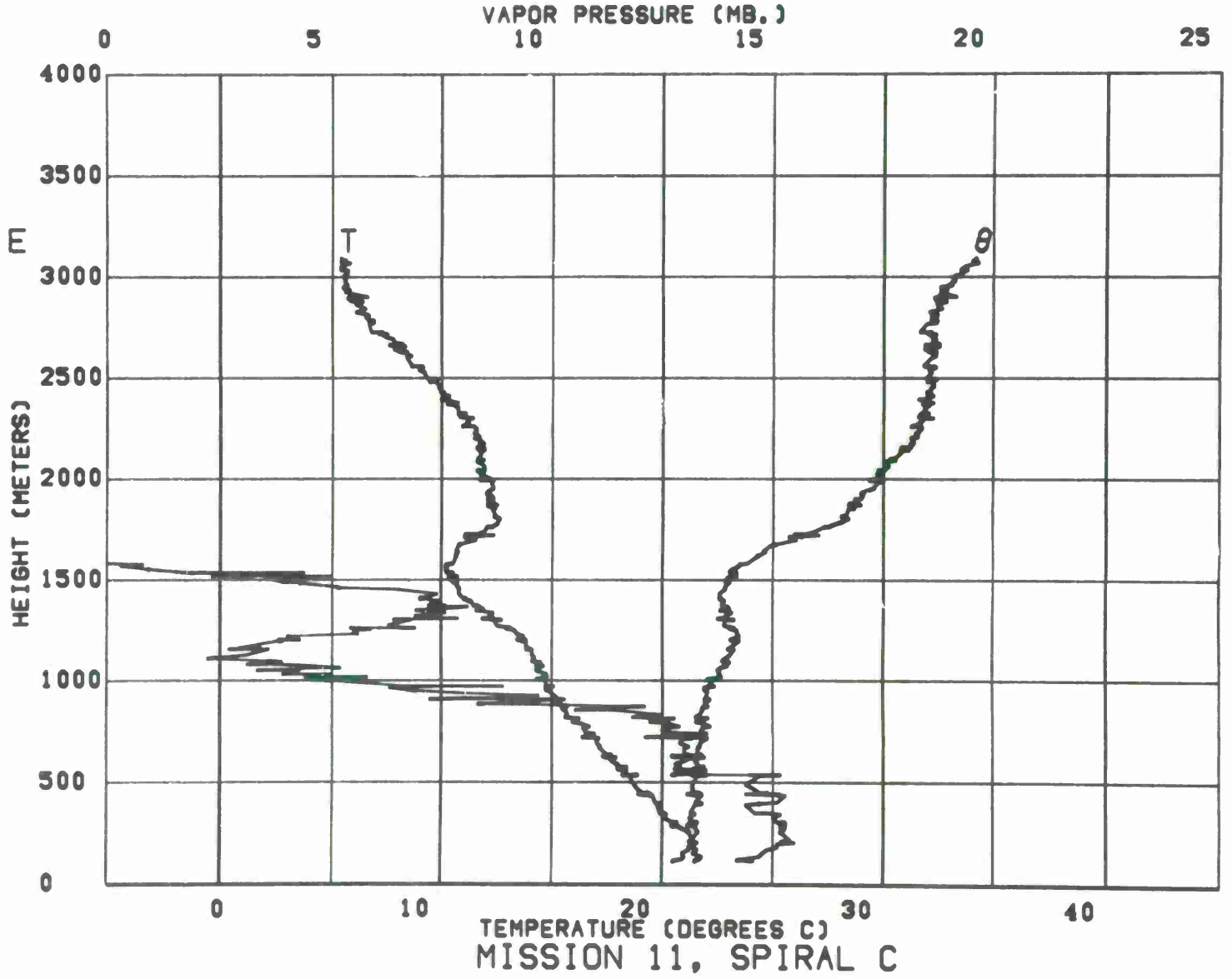


MISSION 11, SPIRAL B


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
TEMPERATURE (DEGREES C)
0
10
20
30
40
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
θ
T
E
MISSION 11, SPIRAL B



MISSION 11, SPIRAL C



MISSION 11, SPIRAL C

MISSION NO. 12

Date: 23 March 1969

Data were obtained for seven spirals and five ascents along Flight Path VIII, westerly from Key West.

Spiral	Location	Spiral Start Time Z	Local
A	a. Key West	0712	0212
B	b. 24-35 N, 82-37 W	0748	0248
Climb 1	b-c	0806	0306
C	c. 24-35 N, 83-32 W	0828	0328
Climb 2	c-d	0845	0345
D	d. 24-35 N, 84-26 W	0909	0409
Climb 3	d-e	0926	0426
E	e. 24-35 N, 83-03 W	0952	0452
Climb 4	e-f	1011	0511
F	f. 24-43 N, 81-04 W	1043	0543
Climb 5	f-a	1101	0601
G	a. Key West	1119	0619

NOTE: Spiral C lies in the plane through debf

B6902

SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300
STATUTE MILES

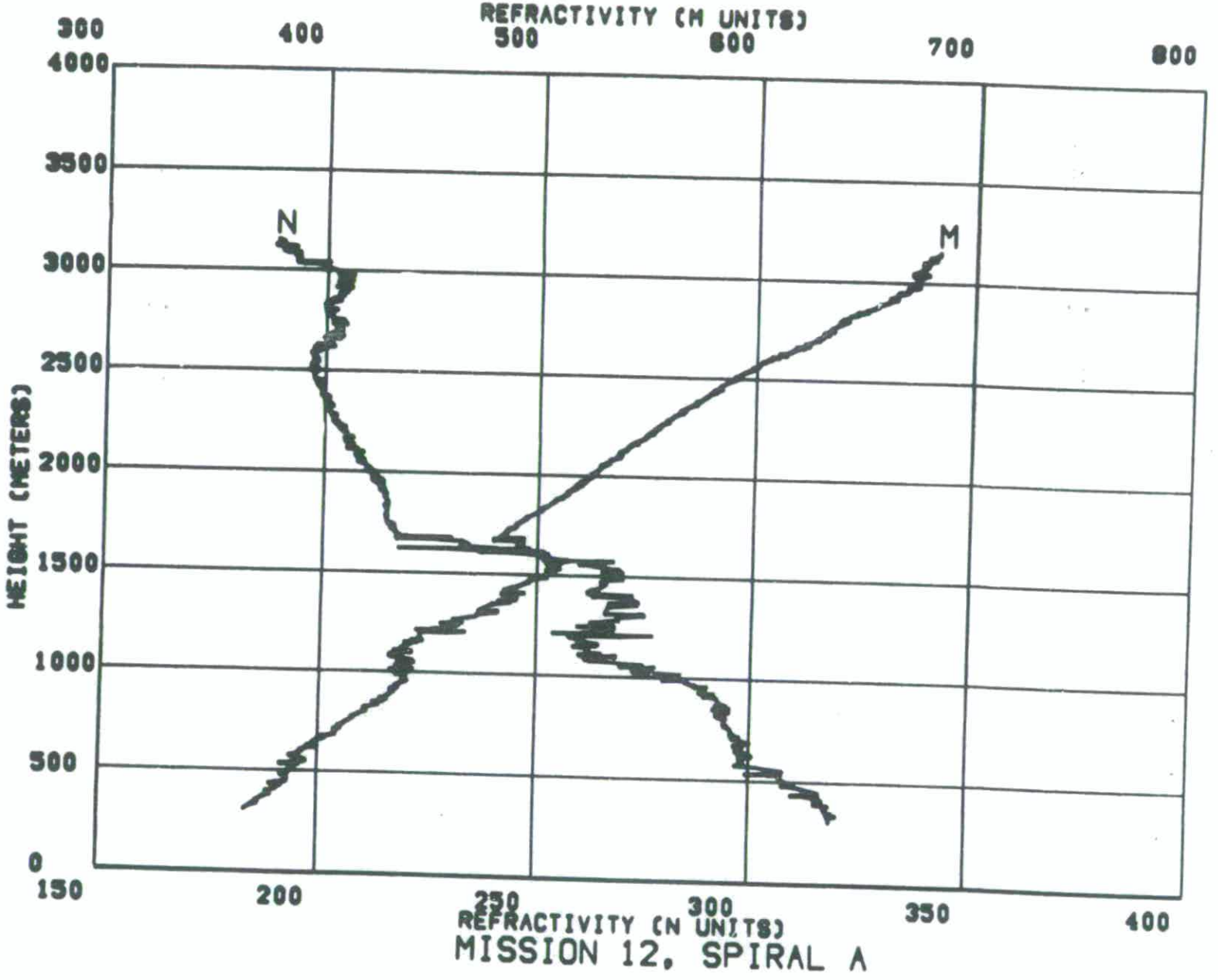
100 50 0 100 200 300 400
KILOMETERS

FLIGHT PATH VIII

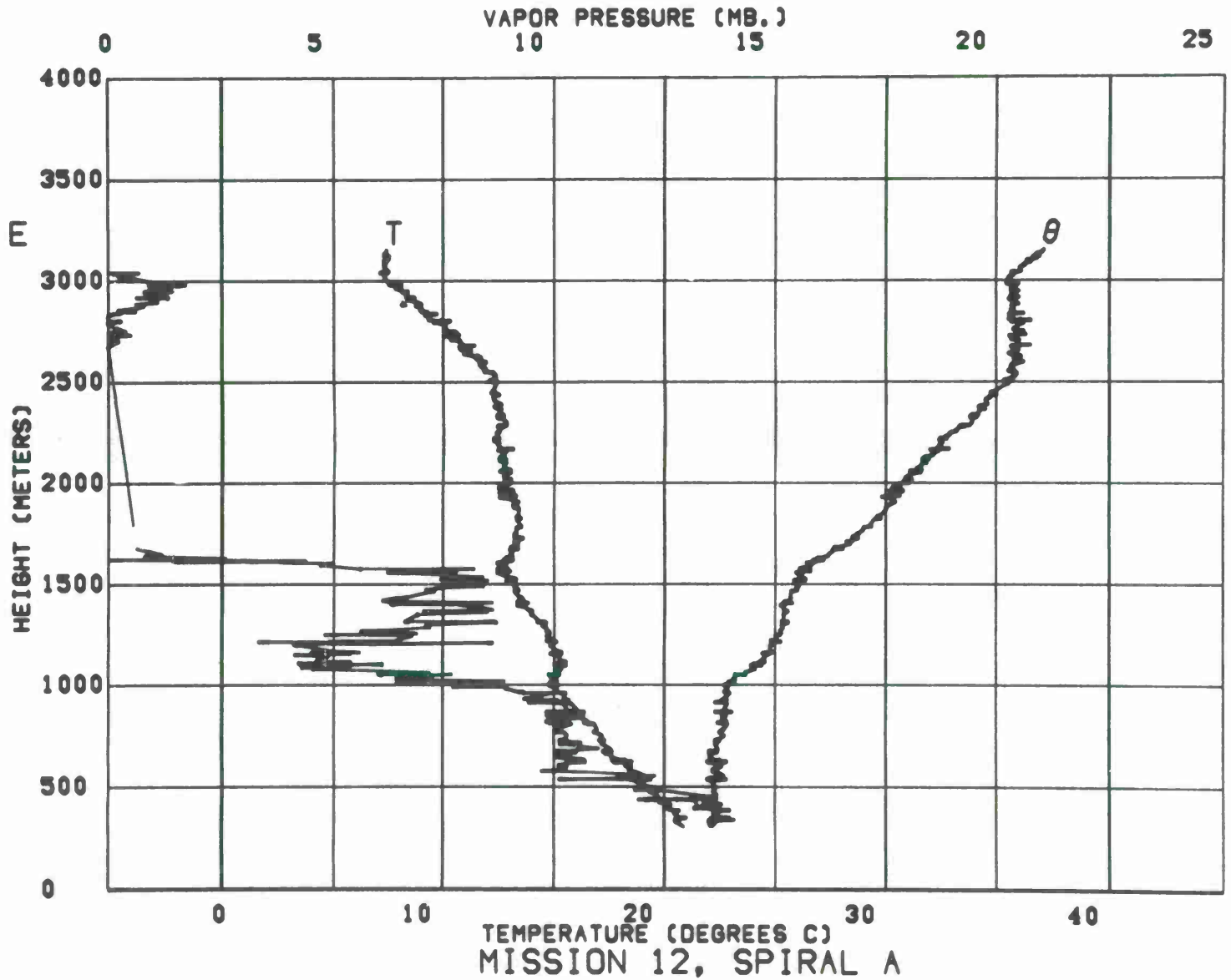
MISSION 12 — 23 MARCH 1969

MISSION 13 — 24 MARCH 1969

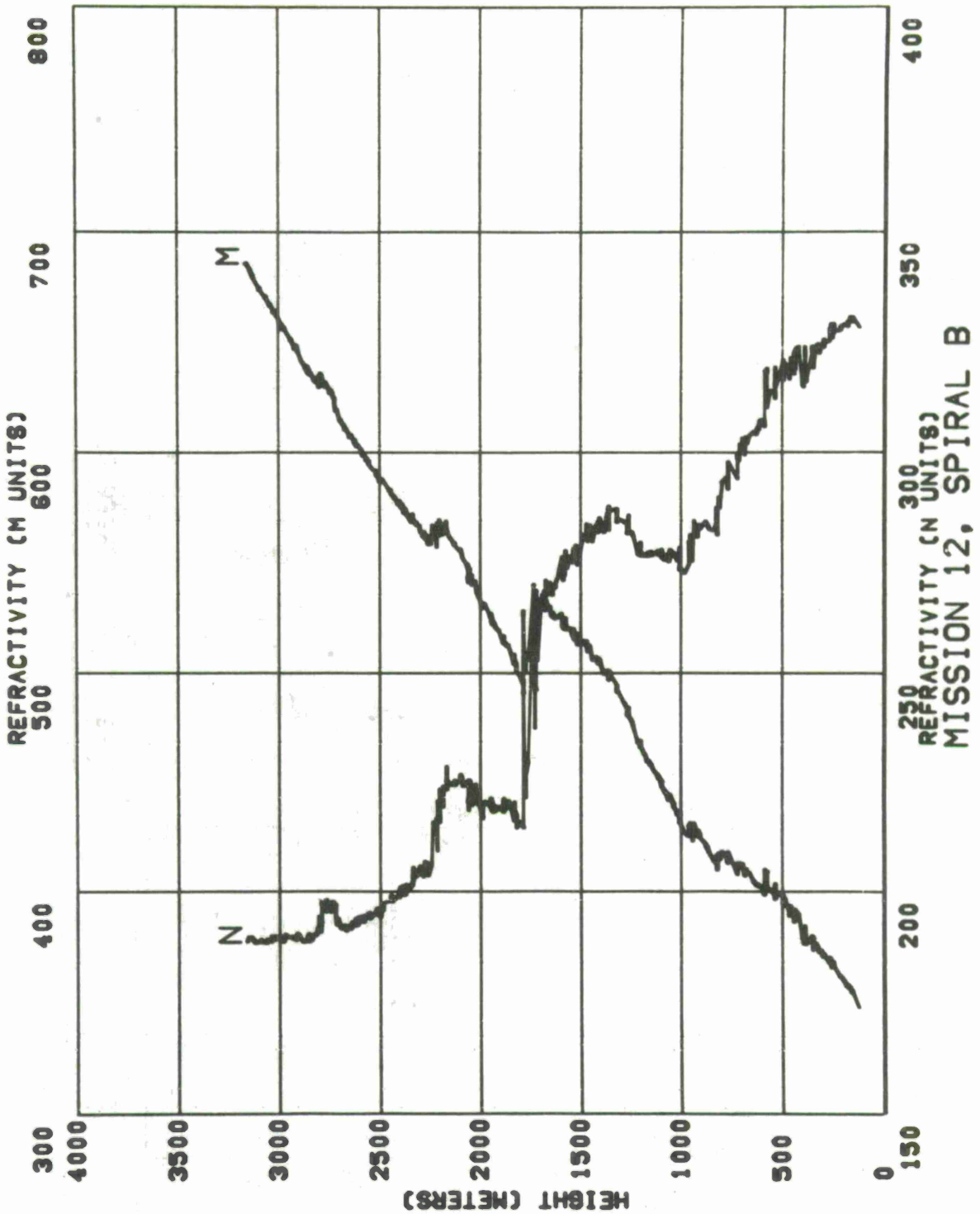
MISSION 14 — 25 MARCH 1969



MISSION 12, SPIRAL A



MISSION 12, SPIRAL A


REFRACTIVITY (M UNITS)
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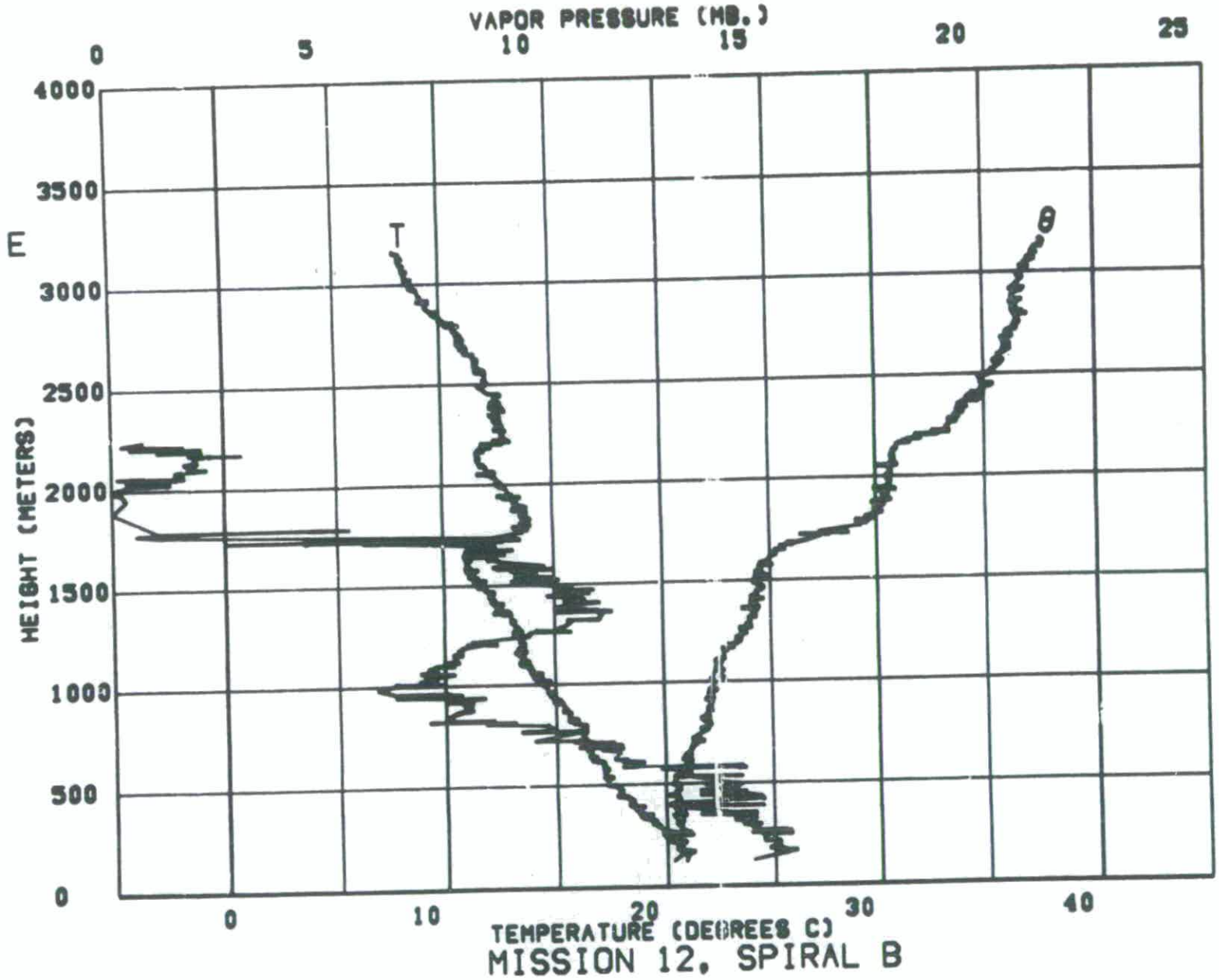
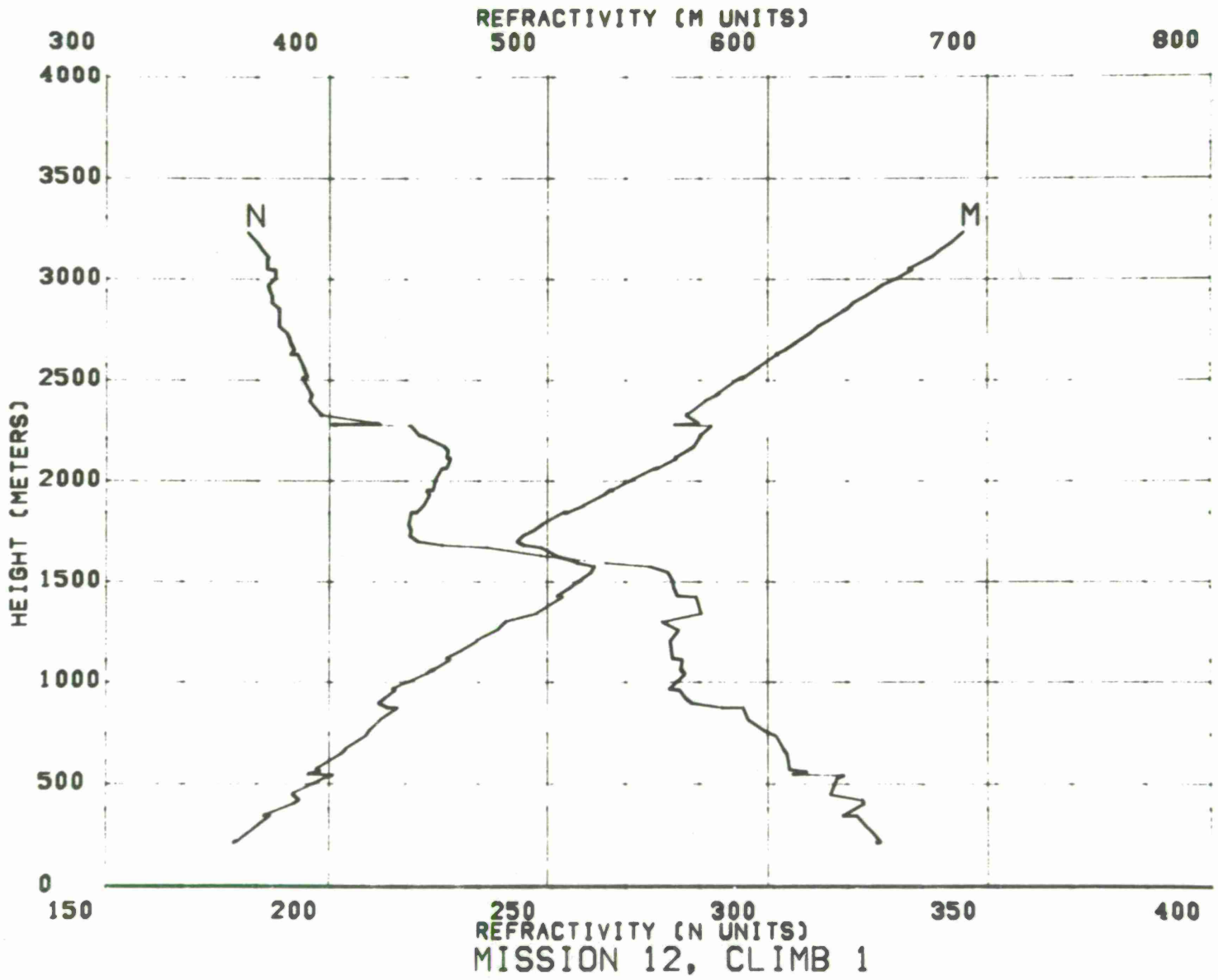
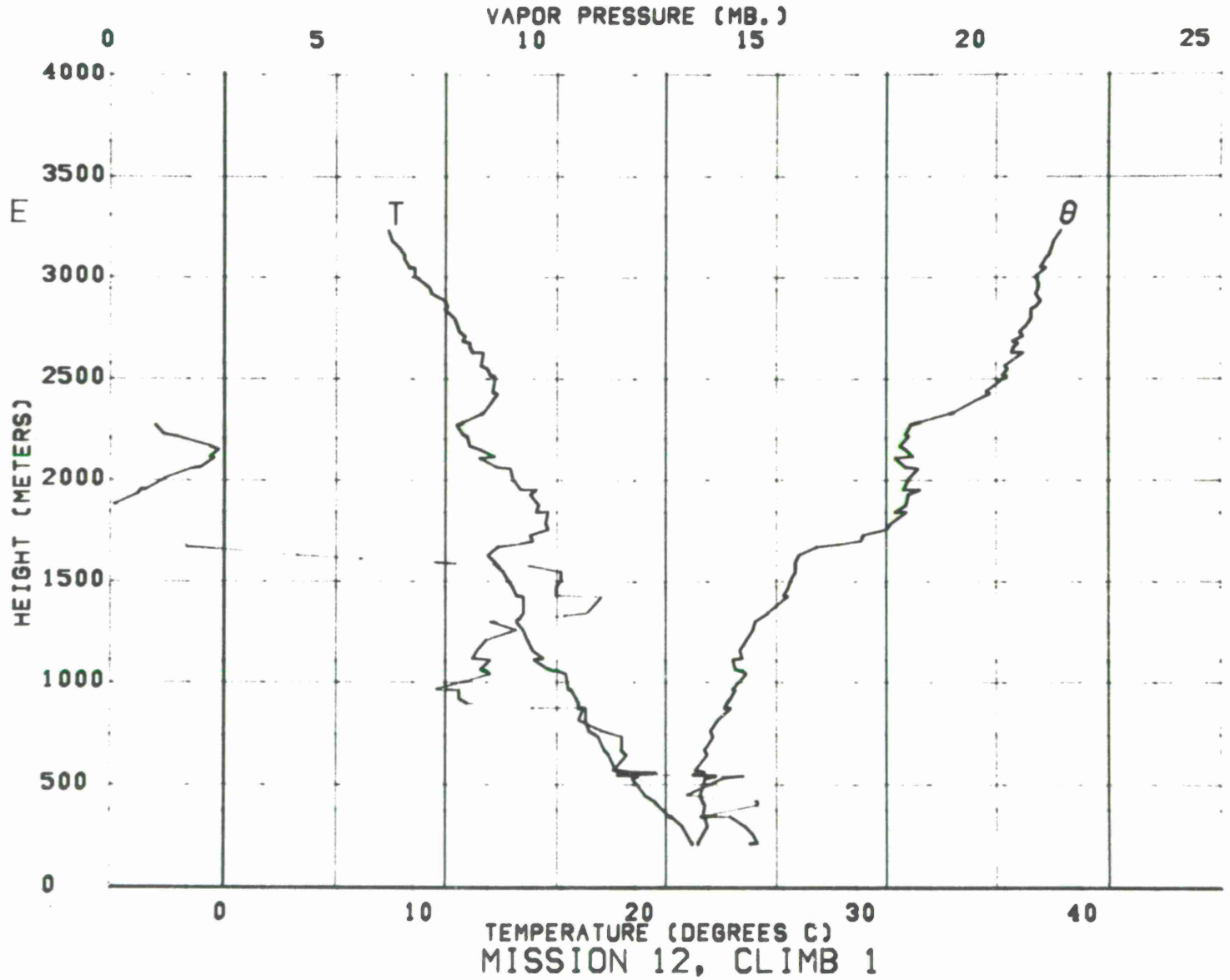
700
600
500
400
300
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
M
N
REFRACTIVITY (N UNITS)
400
350
300
250
200
150
MISSION 12, SPIRAL B



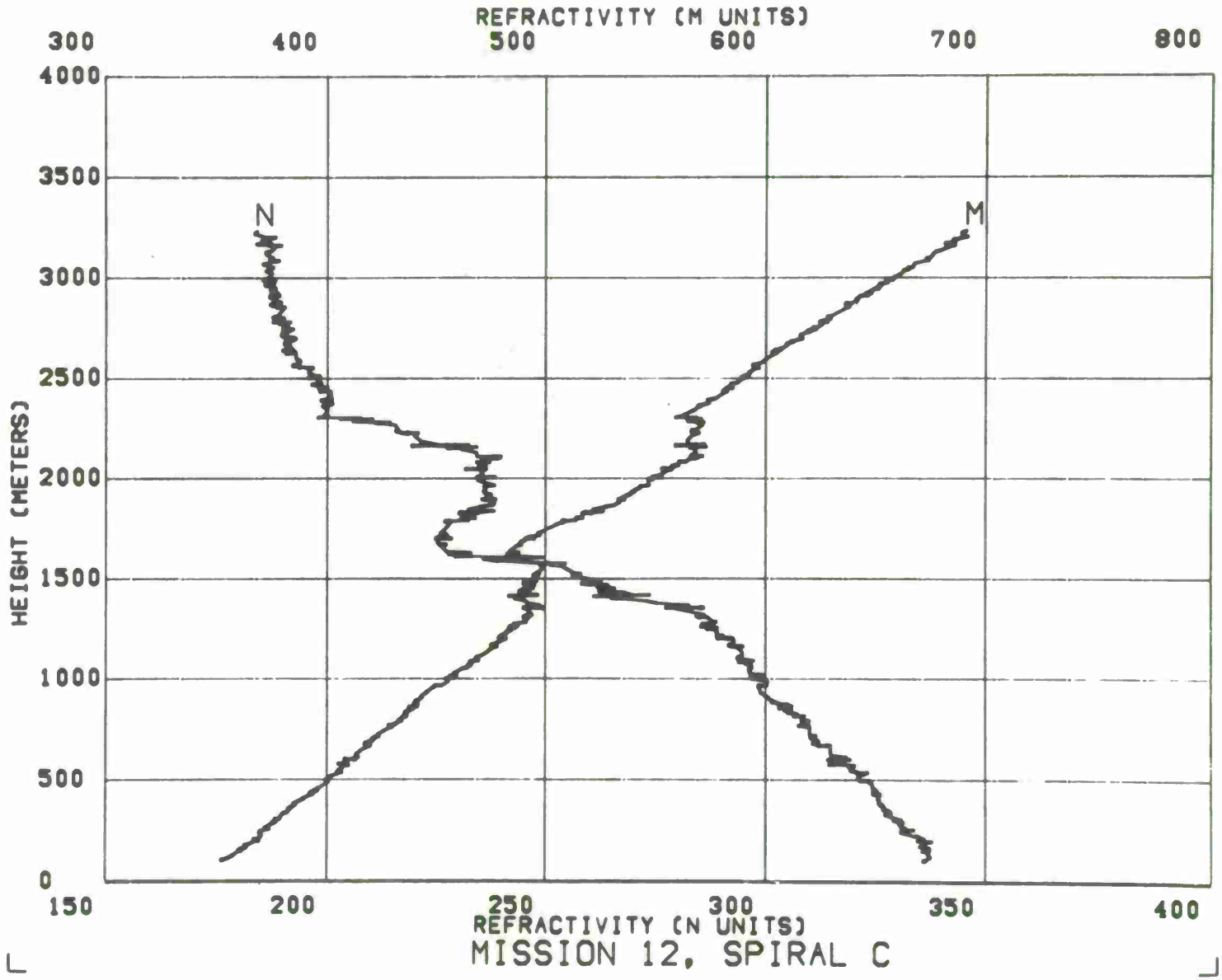
MISSION 12, SPIRAL B



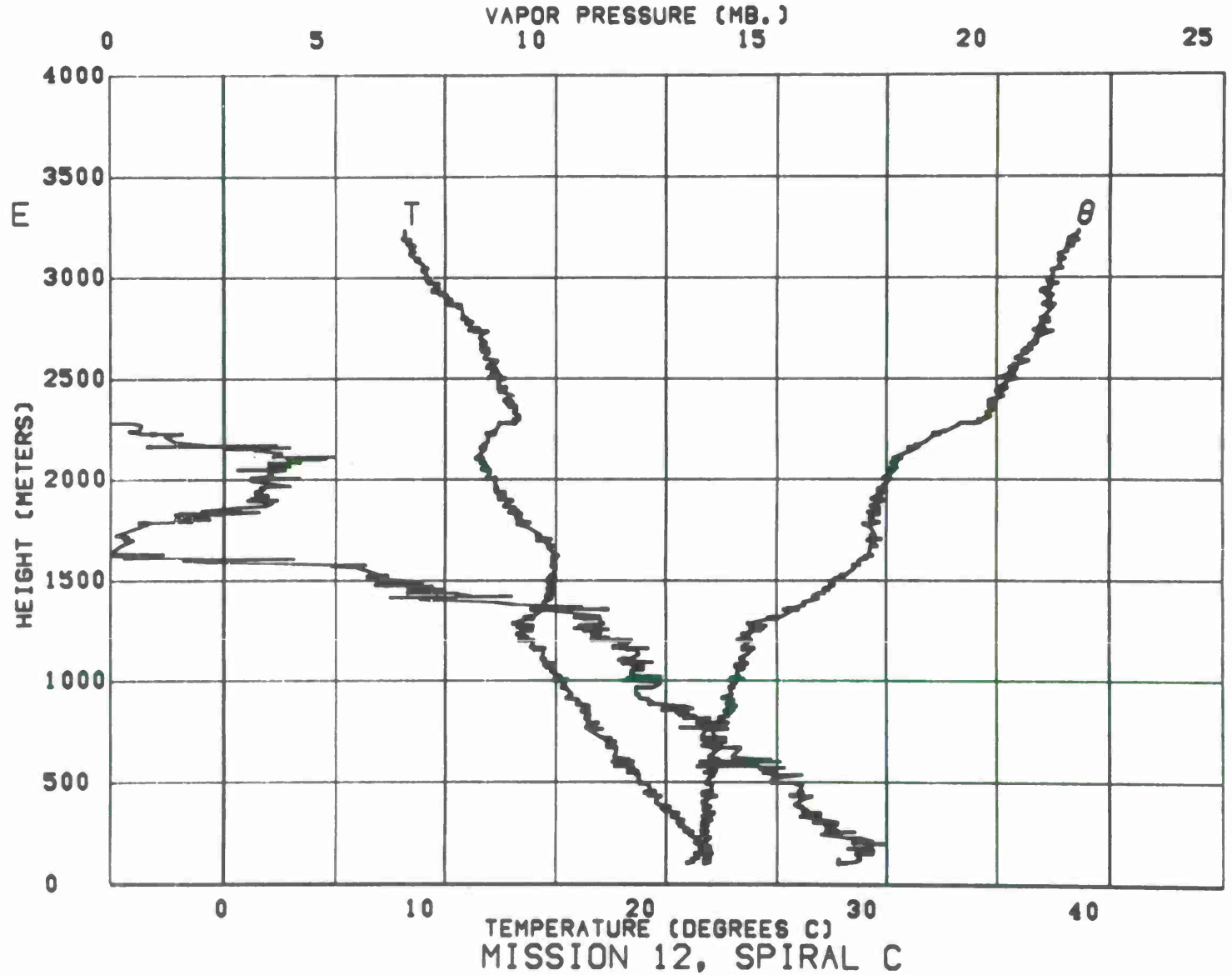
MISSION 12, CLIMB 1



MISSION 12, CLIMB 1



MISSION 12, SPIRAL C


VAPOR PRESSURE (MB.)
0
5
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4000
3500
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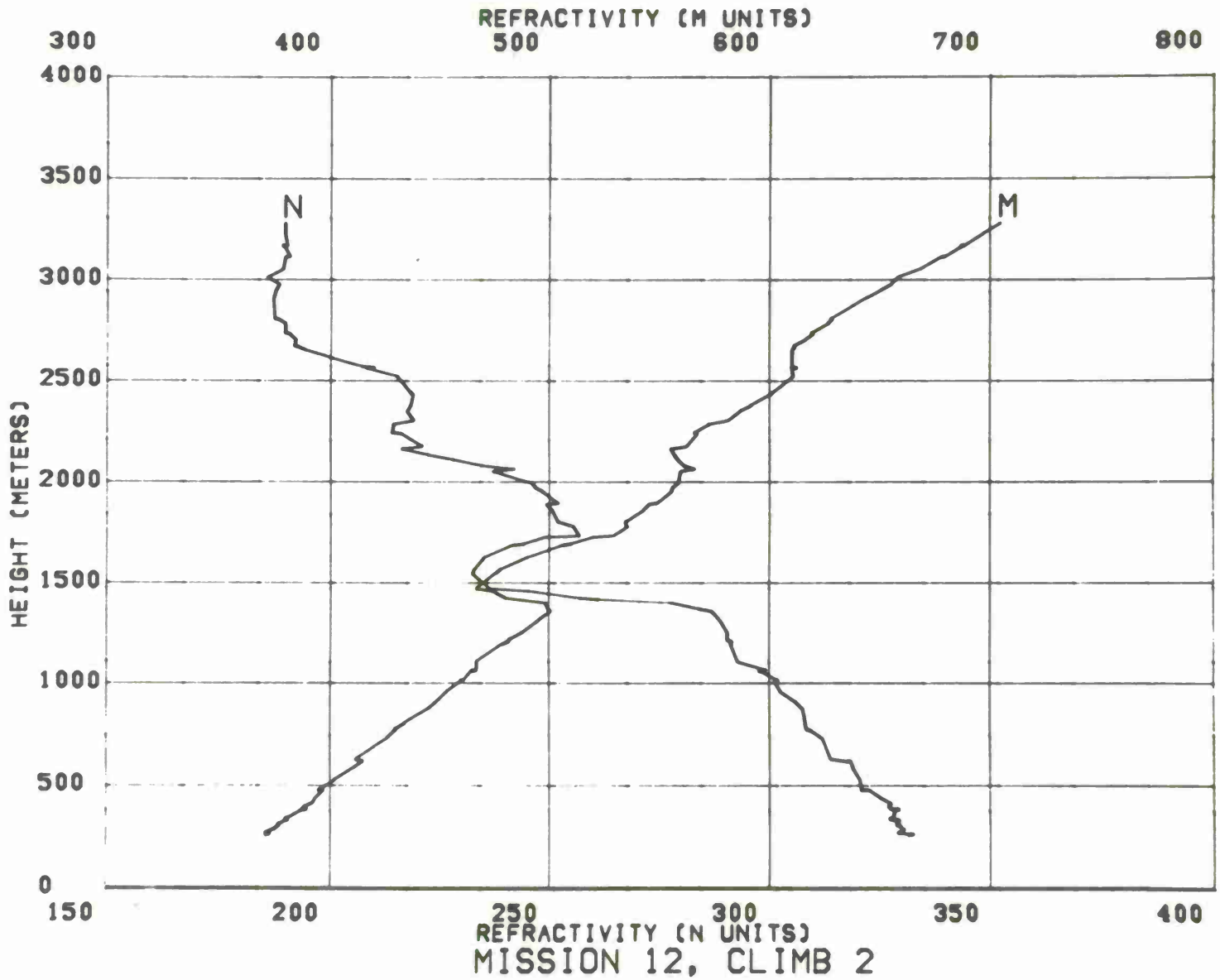
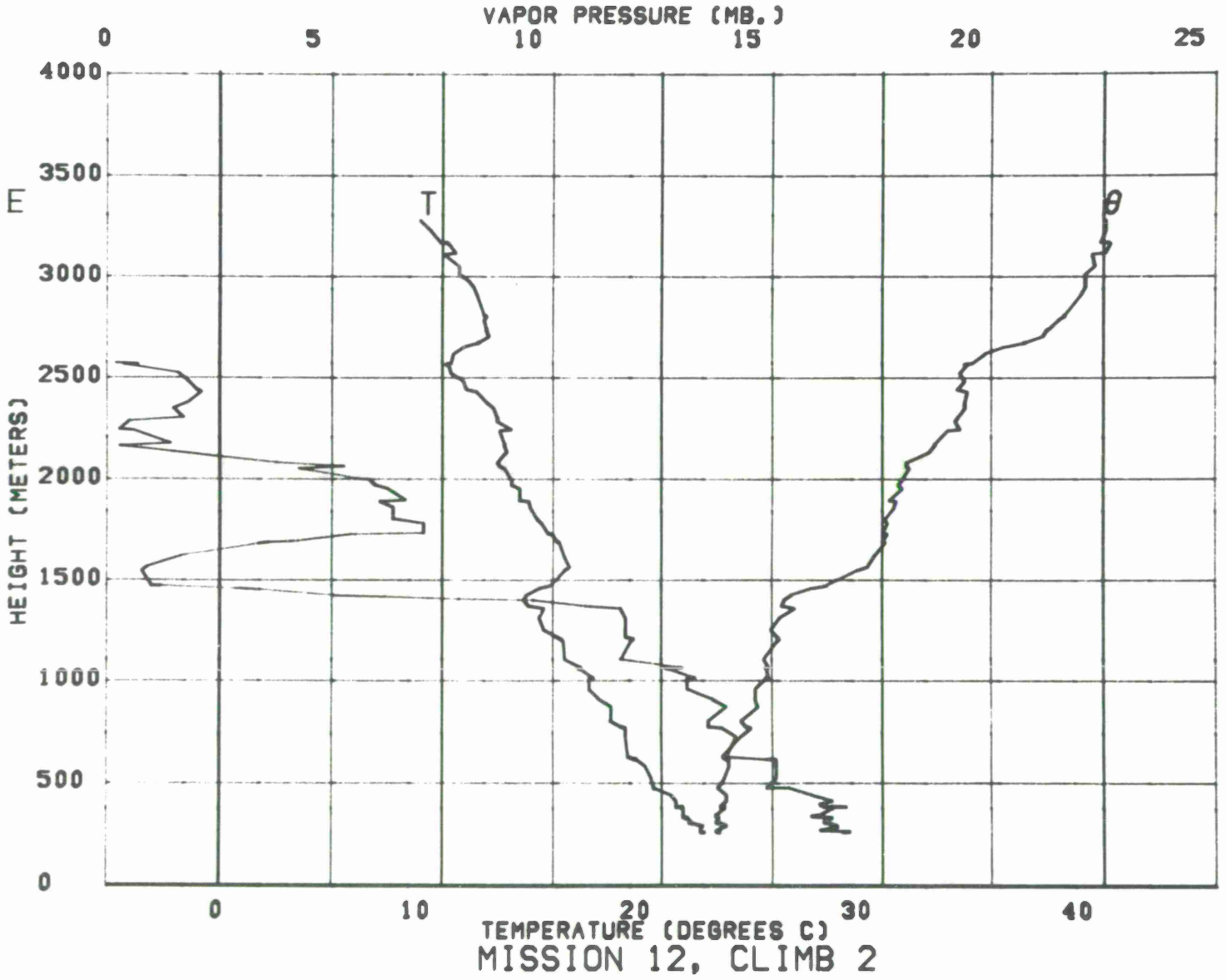
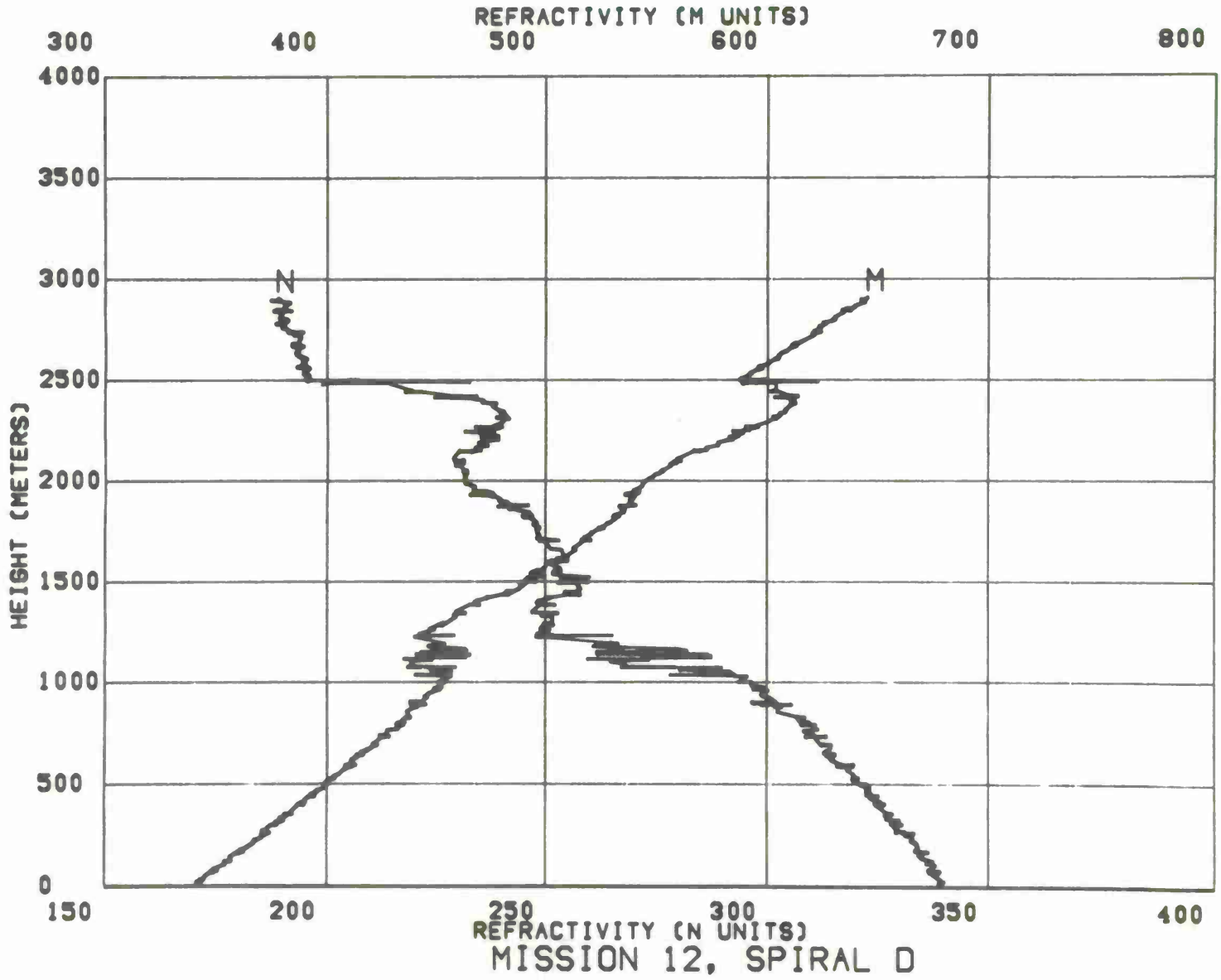
2500
2000
1500
1000
500
0
M
HEIGHT (METERS)
T
θ
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 12, SPIRAL C

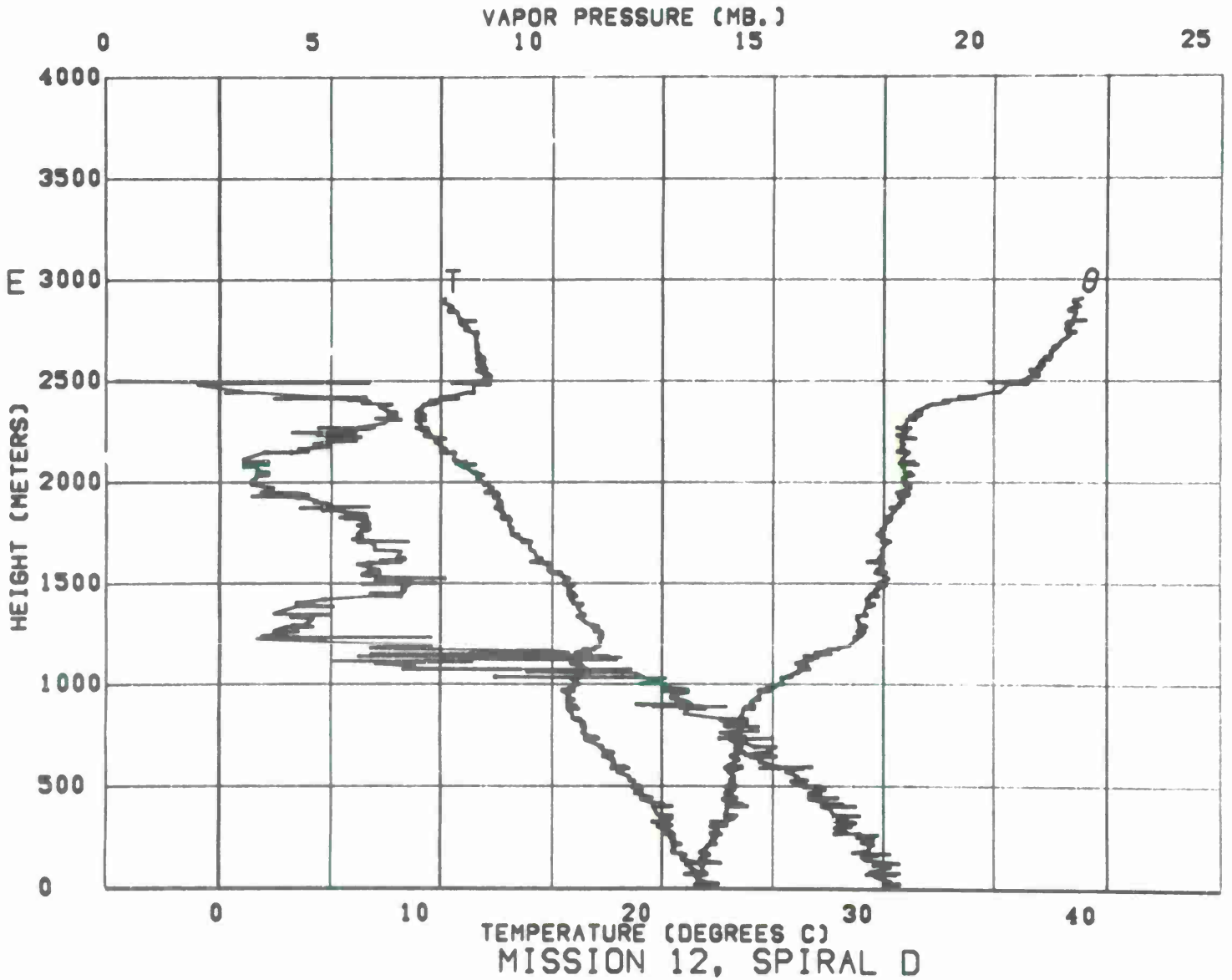


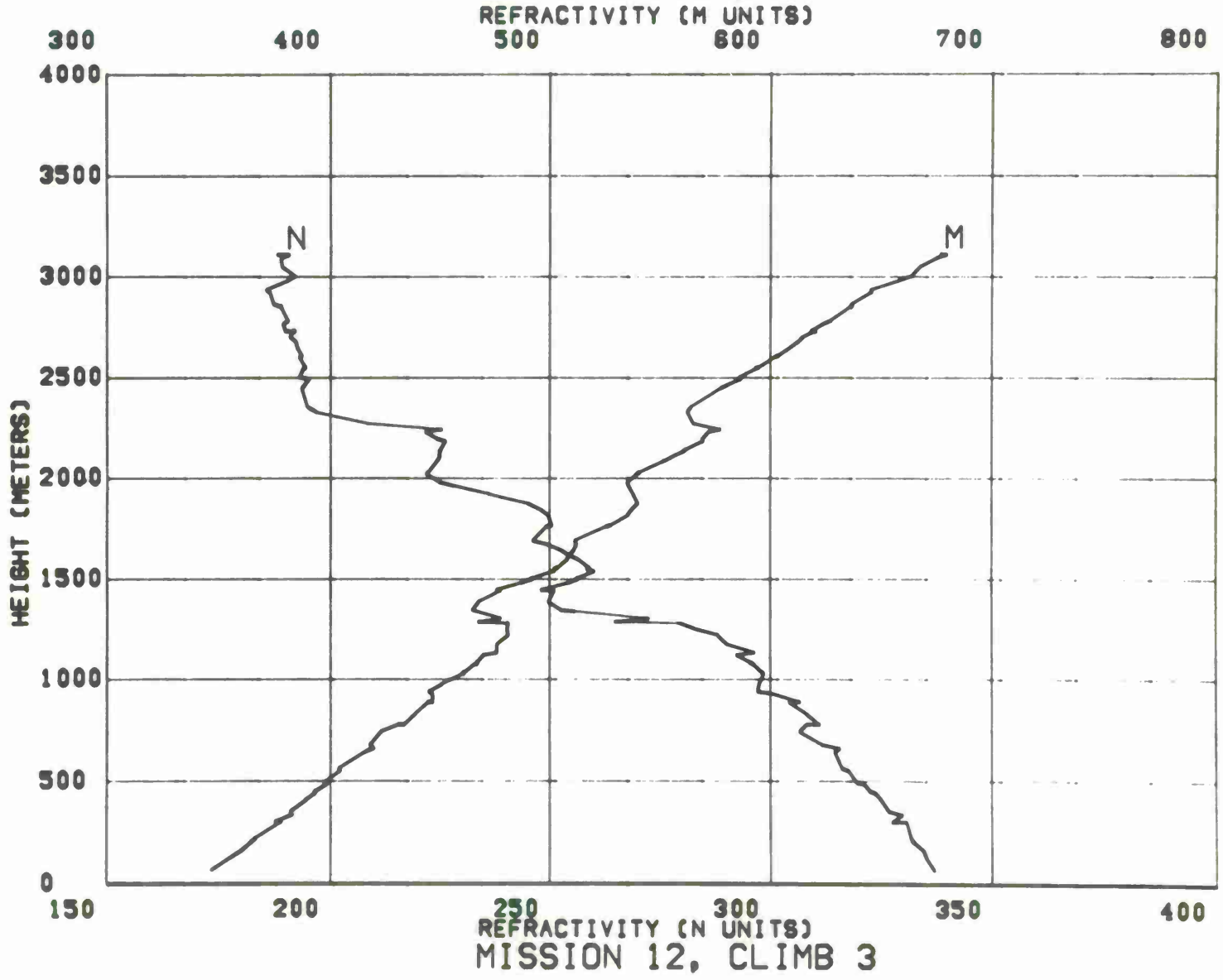
MISSION 12, CLIMB 2


VAPOR PRESSURE (MB.)
0
5
10
15
20
25
4000
3500
3000
2500
2000
1500
1000
500
0
M
HEIGHT (METERS)
T
θ
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 12, CLIMB 2

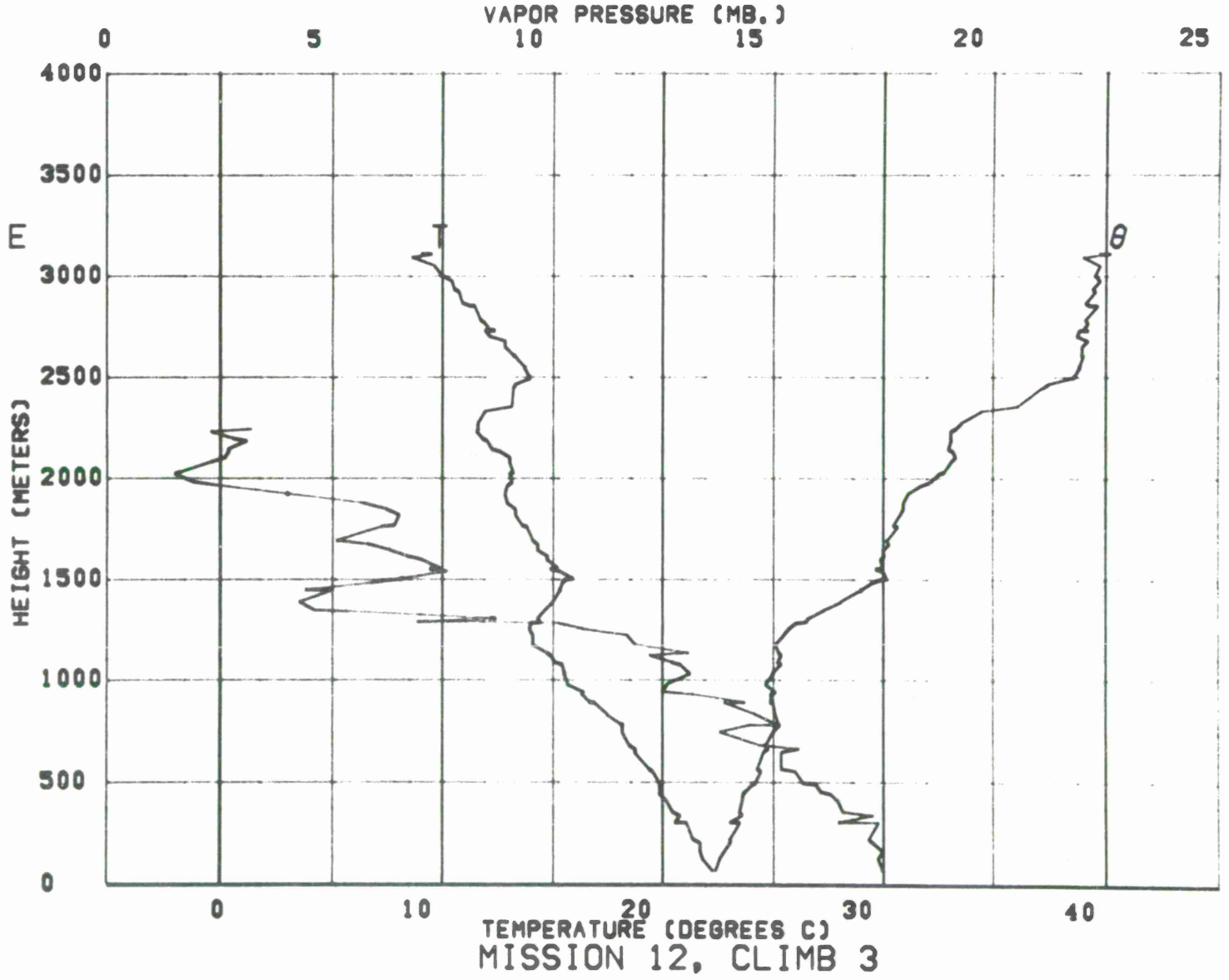


MISSION 12, SPIRAL D

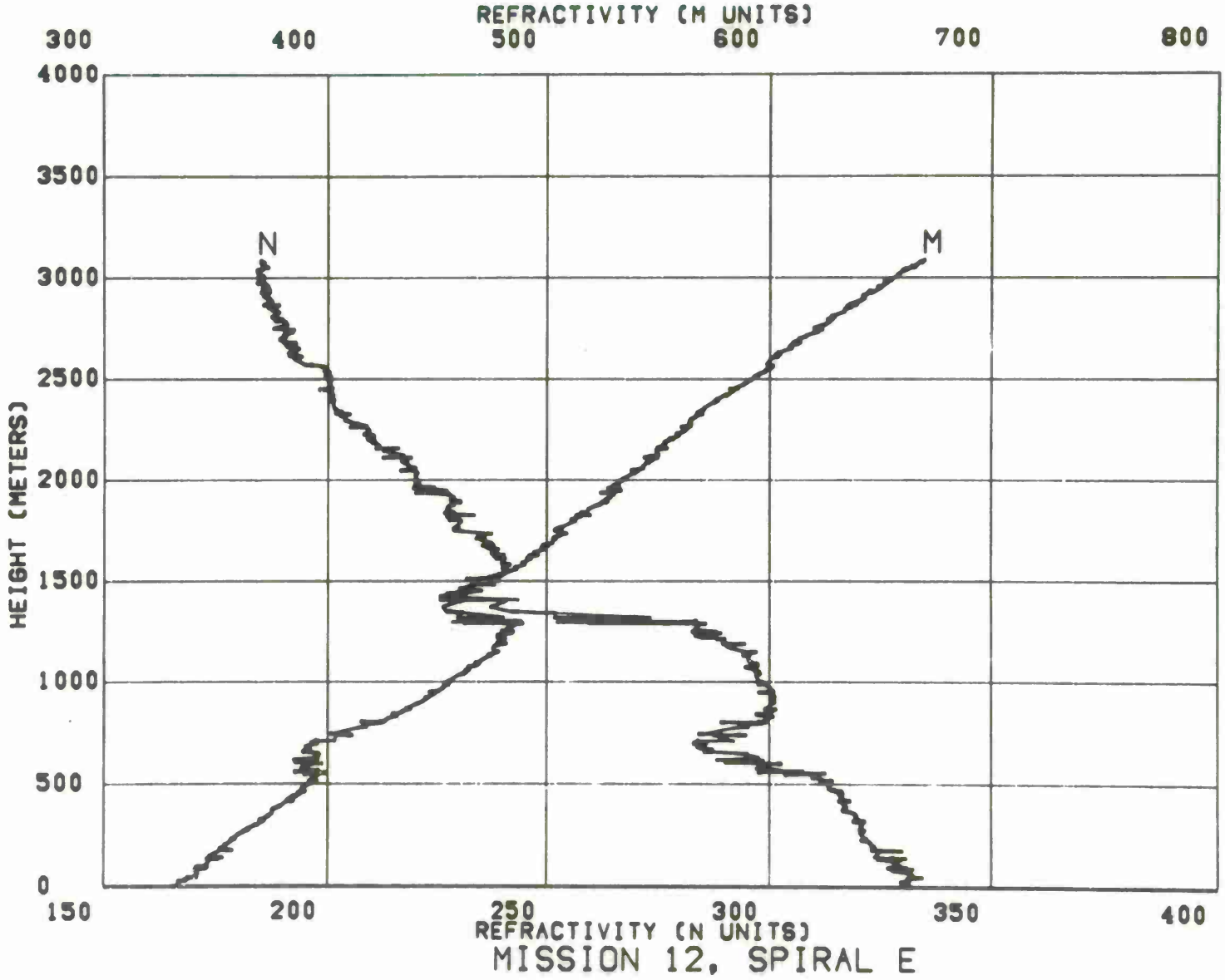

VAPOR PRESSURE (MB.)
0
5
10
15
20
25
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
T
θ
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 12, SPIRAL D



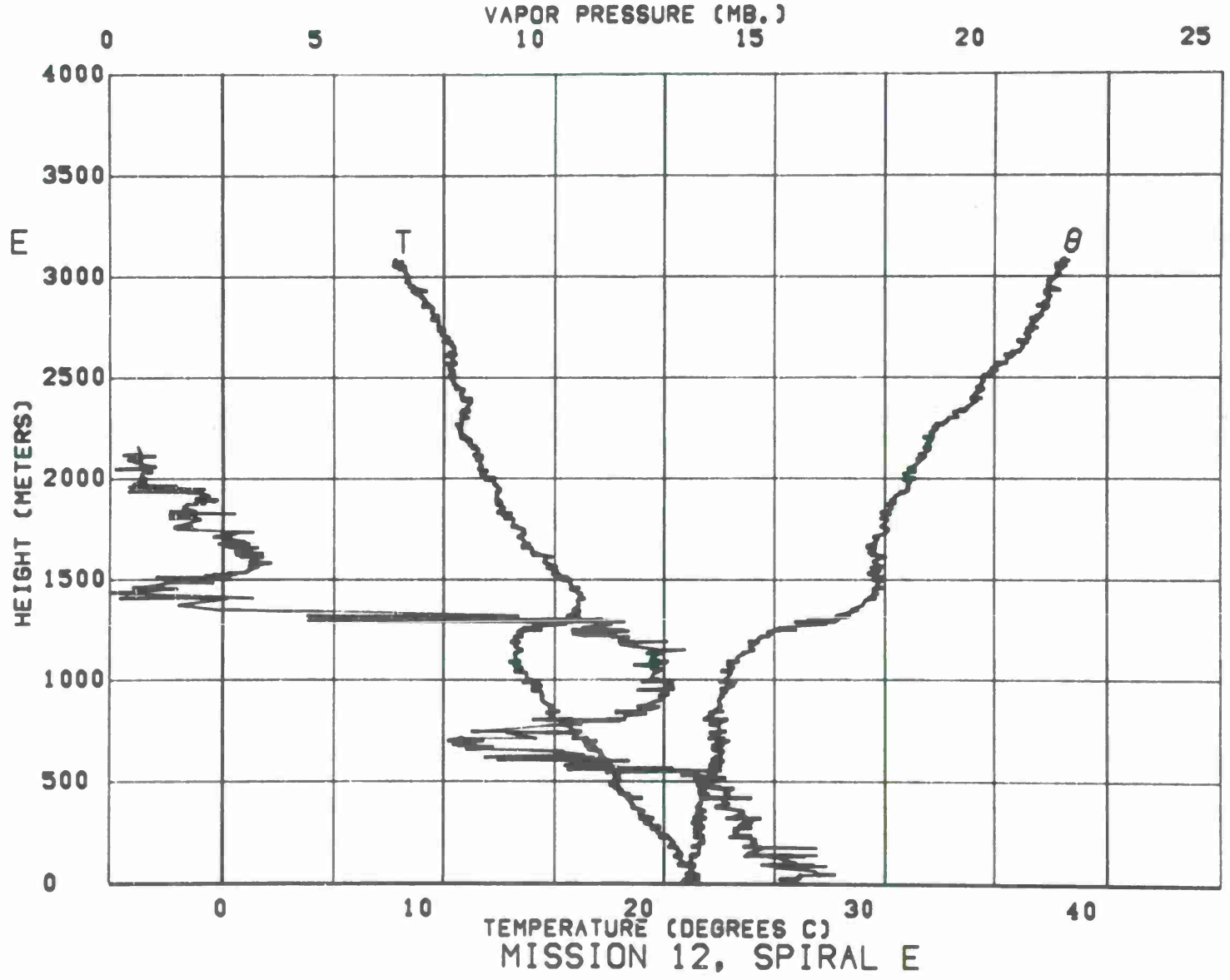
MISSION 12, CLIMB 3



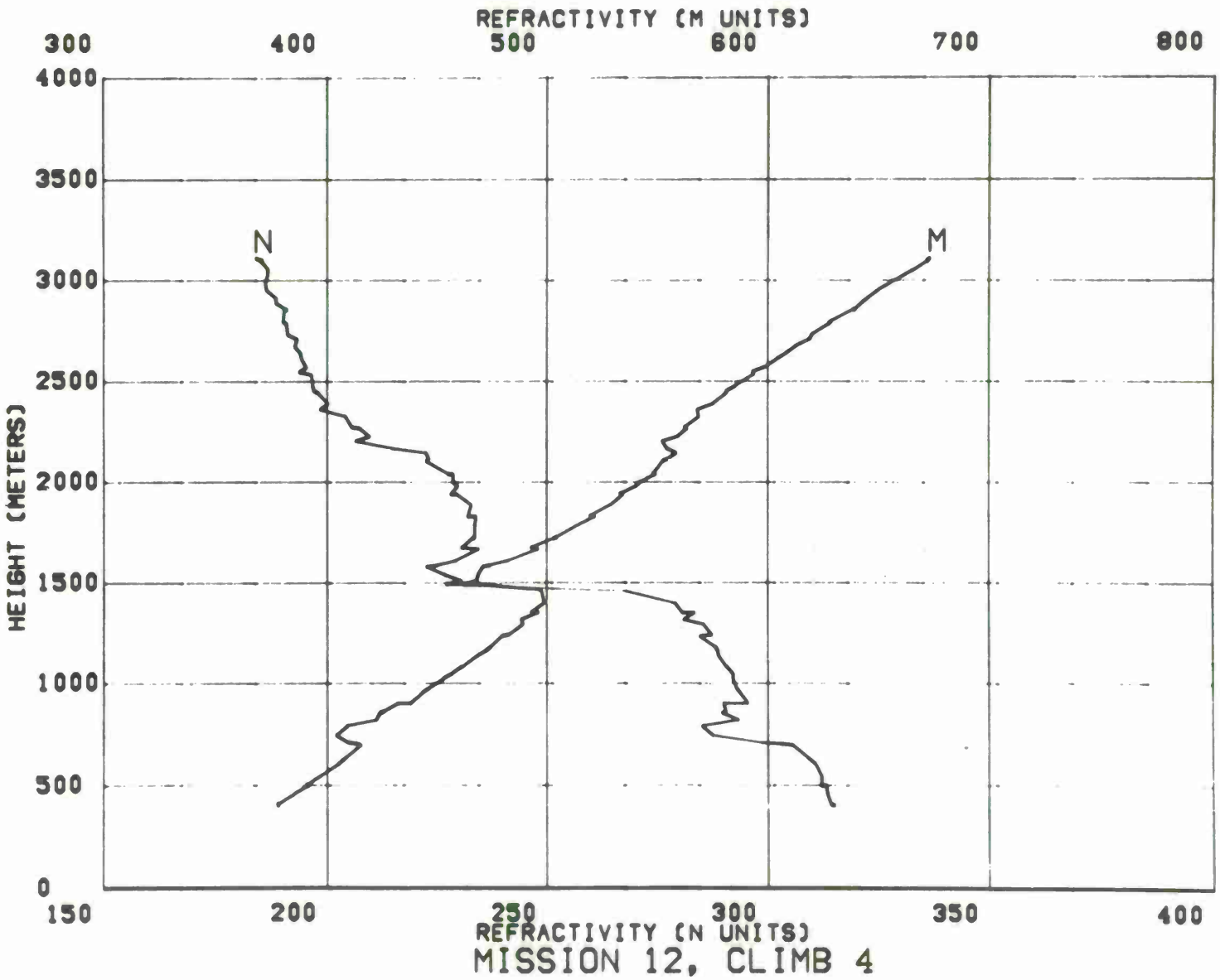
MISSION 12, CLIMB 3



MISSION 12, SPIRAL E



MISSION 12, SPIRAL E


REFRACTIVITY (M UNITS)
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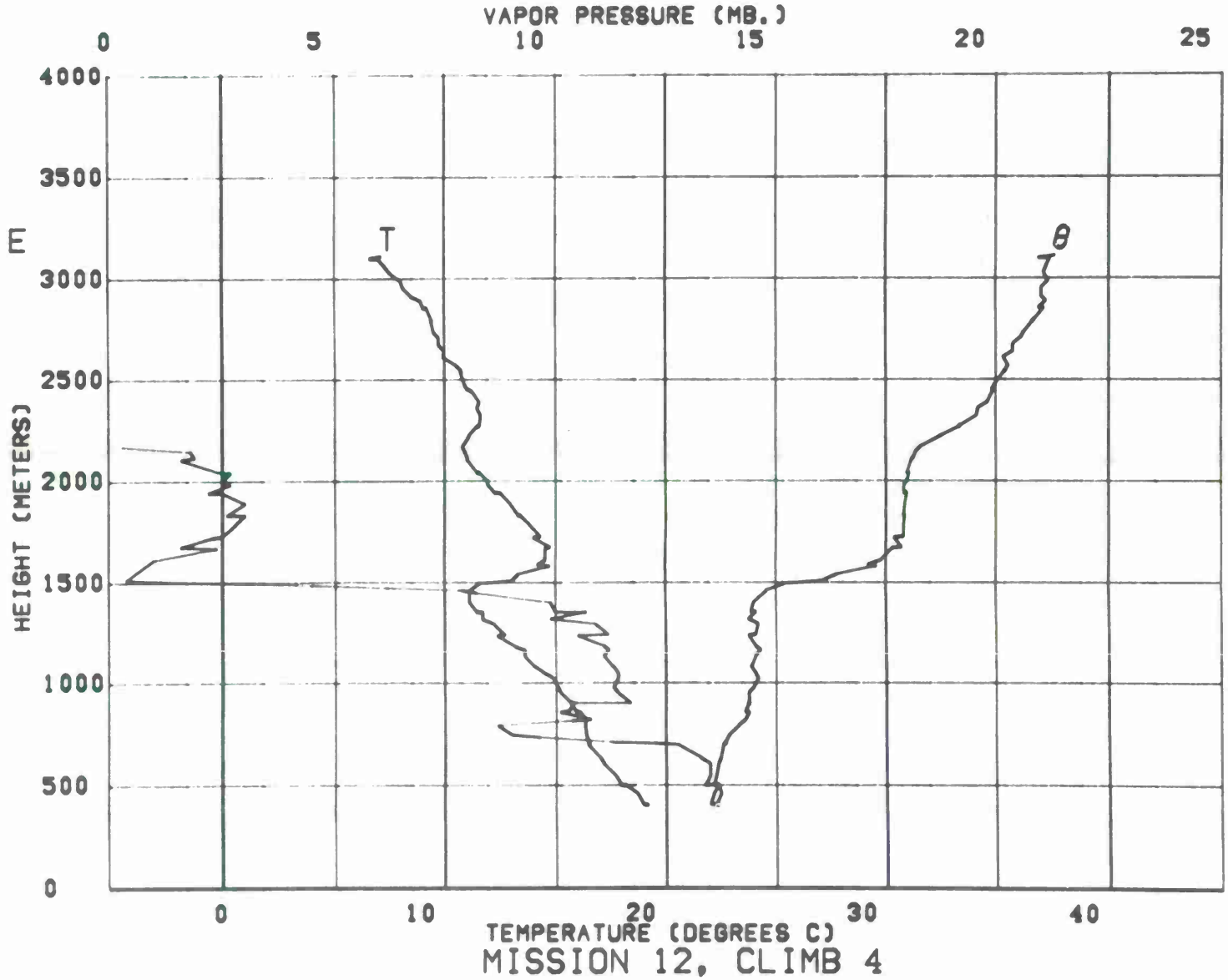
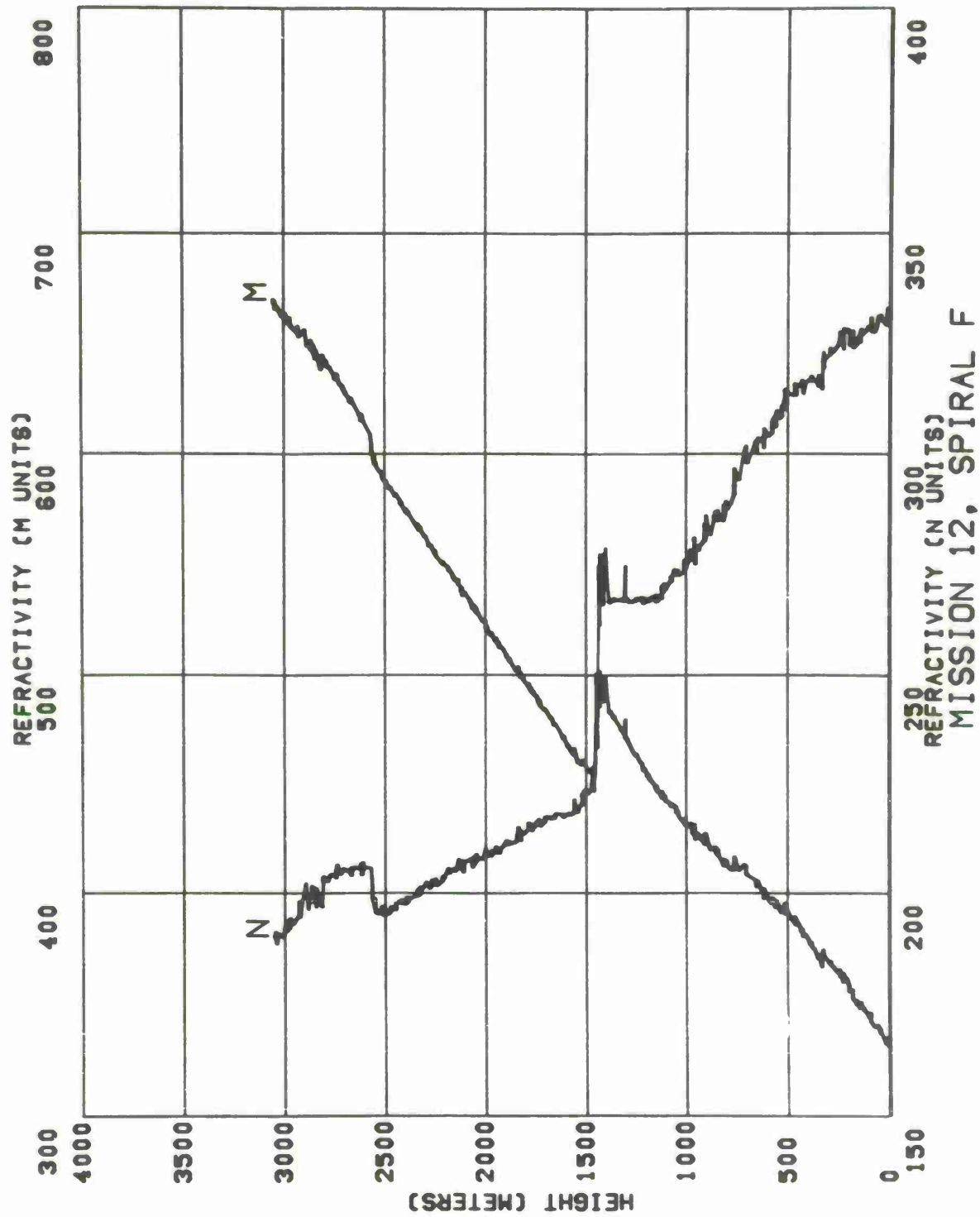
600
700
800
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
N
M
150
200
250
300
350
400
REFRACTIVITY (N UNITS)
MISSION 12, CLIMB 4



MISSION 12, CLIMB 4


MISSION 12, SPIRAL F
REFRACTIVITY (M UNITS)
REFRACTIVITY (N UNITS)
HEIGHT (METERS)
M
N
300
400
500
600
700
800
150
200
250
300
350
400
0
500
1000
1500
2000
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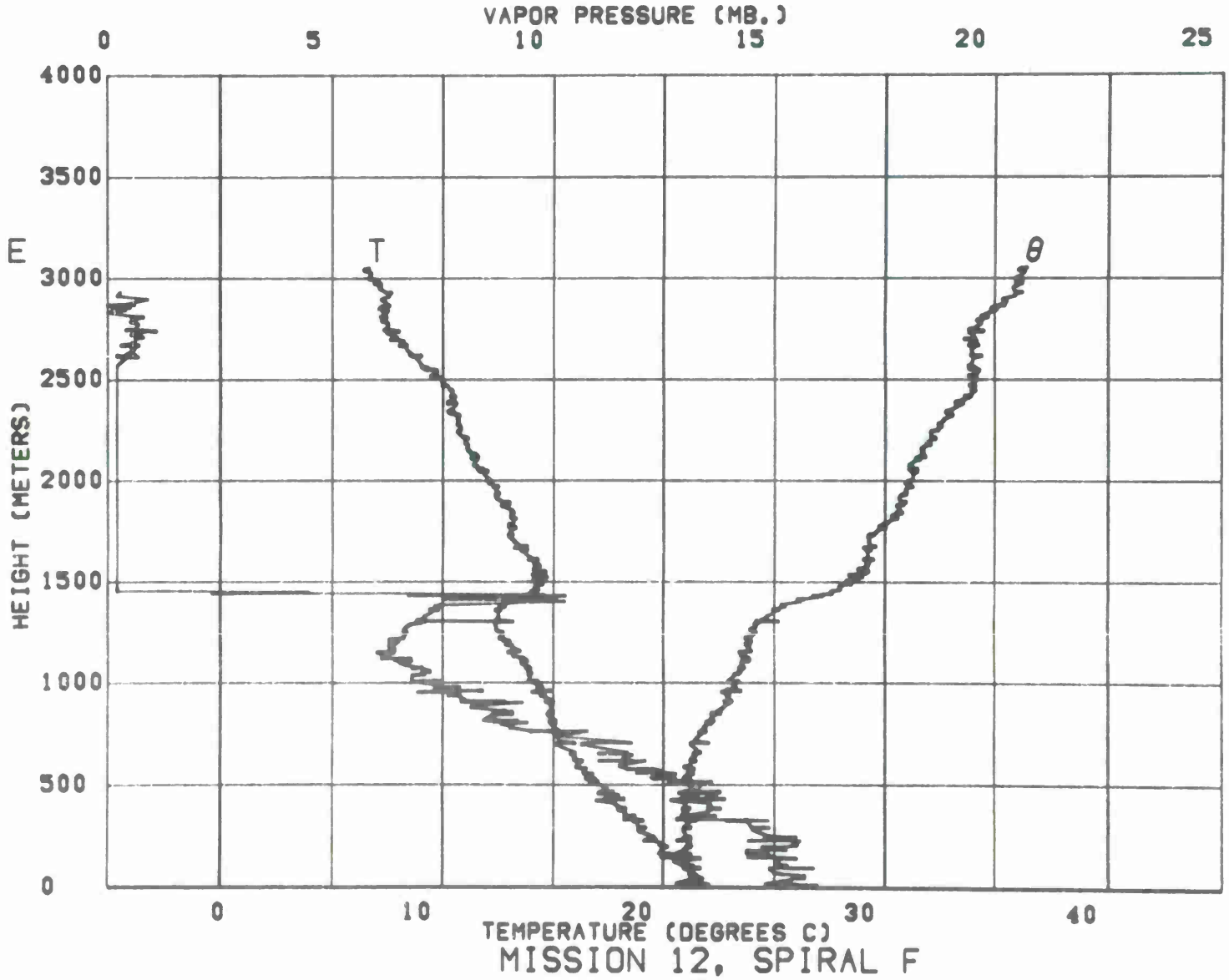
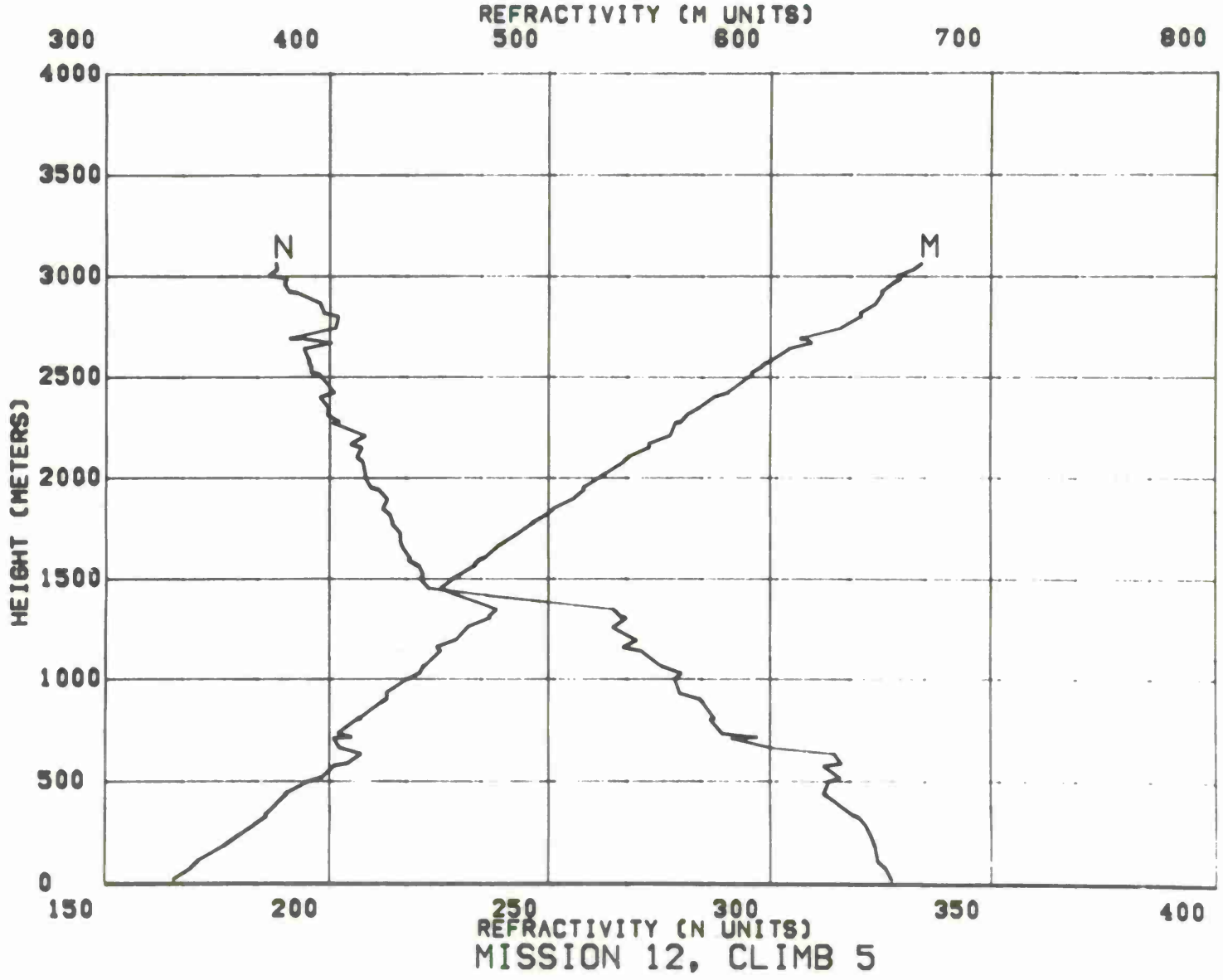
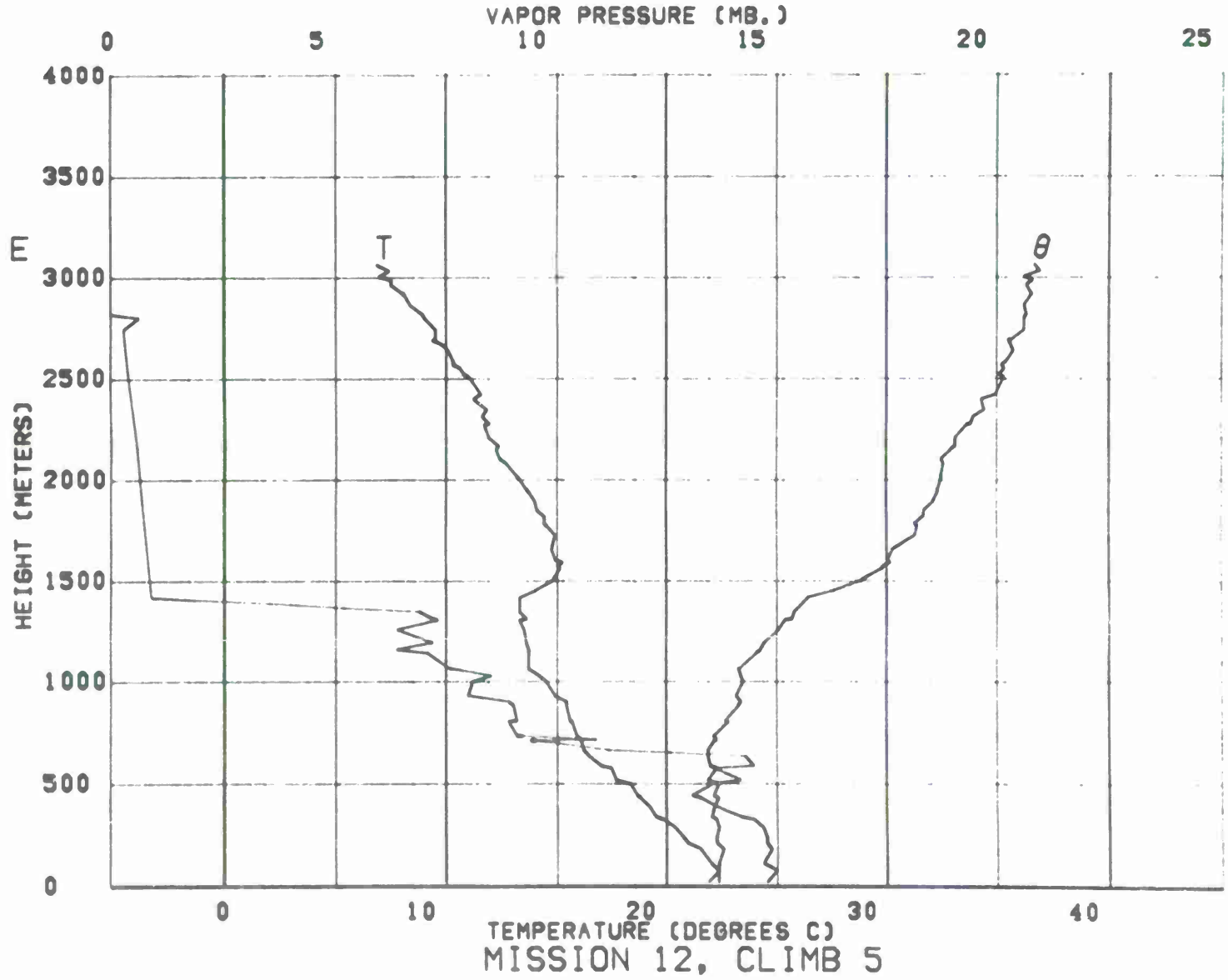
3000
3500
4000



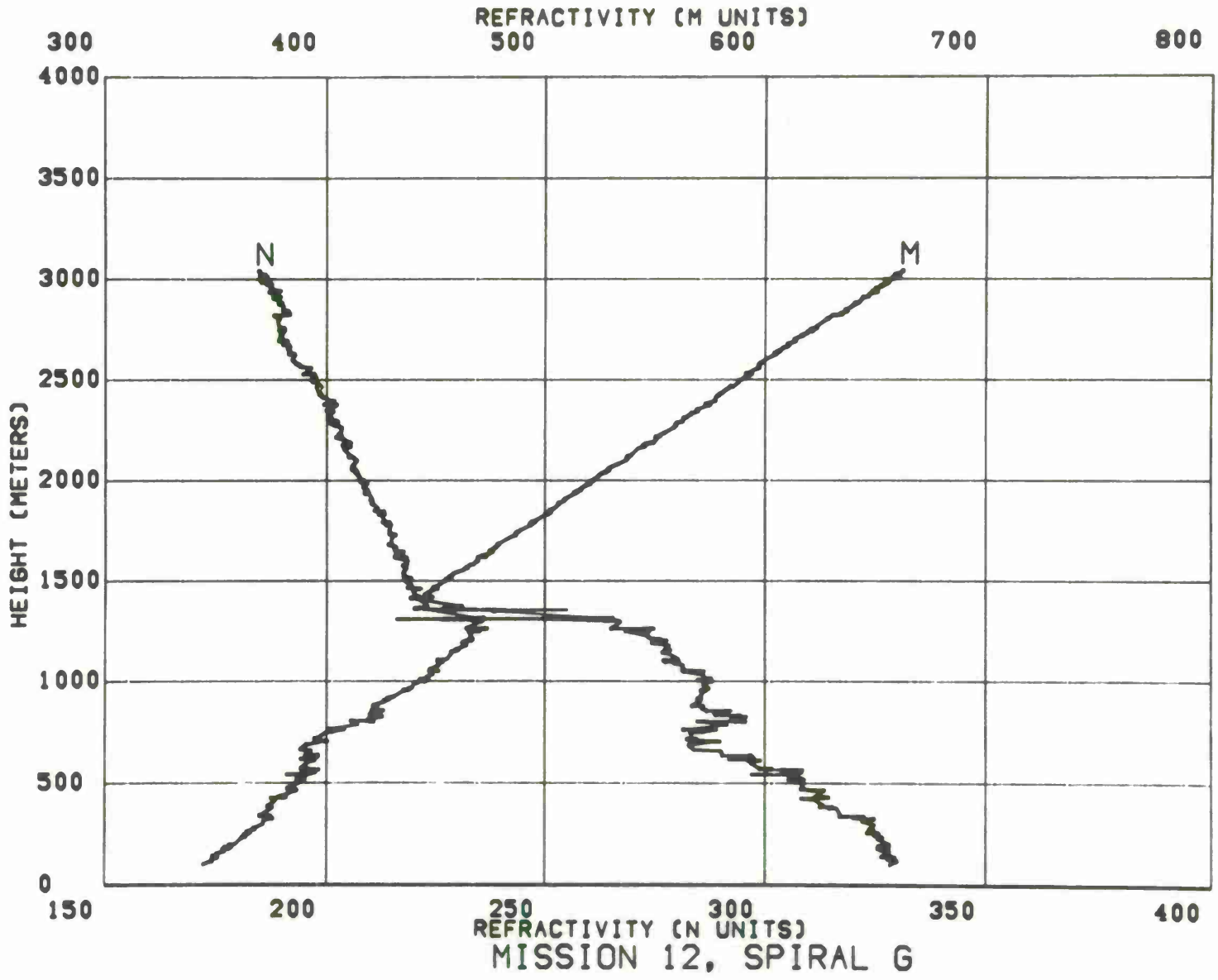
MISSION 12, SPIRAL F



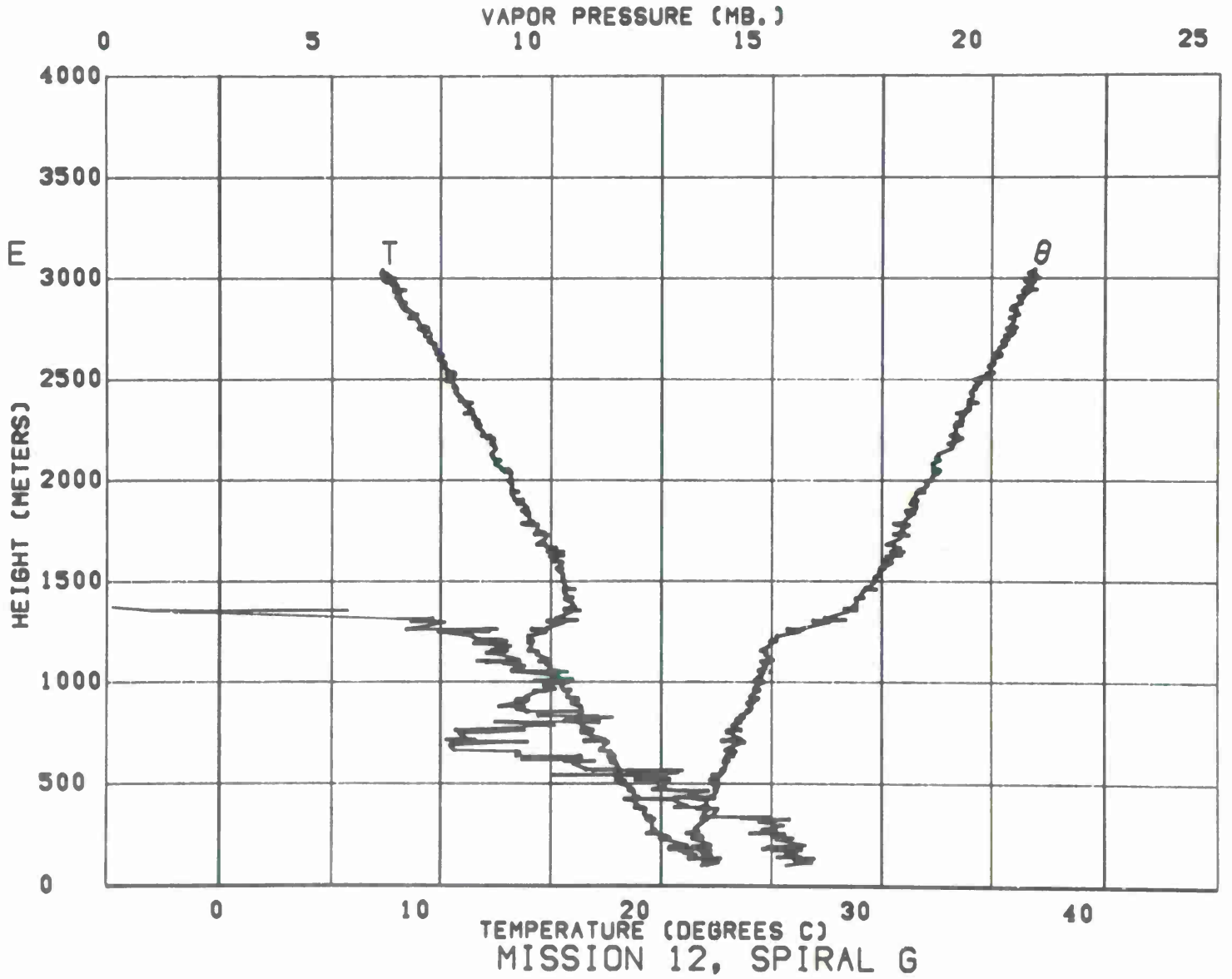
MISSION 12, CLIMB 5



MISSION 12, CLIMB 5



MISSION 12, SPIRAL G



MISSION 12, SPIRAL G

MISSION NO. 13

Date: 24 March 1969

Data were obtained for six spirals and three ascents along Flight Path VIII, westerly from Key West.

Unfortunately, although the analog recordings were very good for the mission (Reference ESD-TR-69-366 , "Caribbean Upper Air Measurements," Technical Report No. I), the digital records were unusable until spiral D was initiated. This difficulty resulted from an intermittent electronic failure in the analog-to-digital recorder and, of course, was not discoverable on the paper tape digital records during flight.

Spiral	Location	Spiral Start Time Z	Local
A	a. Key West	1132	0632
B	b. 24-35 N, 82-37 W	1212	0712
Climb 1	b-c	1236	0736
C	c. 24-35 N, 83-32 W	1257	0757
Climb 2	c-d	1321	0821
D	d. 24-35 N, 84-26 W	1348	0848
Climb 3	d-e	1406	0906
E	e. 24-35 N, 83-03 W	1430	0930
Climb 4			
F	a. Key West	1511	1011

NOTE: Spiral C lies in the plane through deb.

B7093

SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300

STATUTE MILES

100 50 0 100 200 300 400

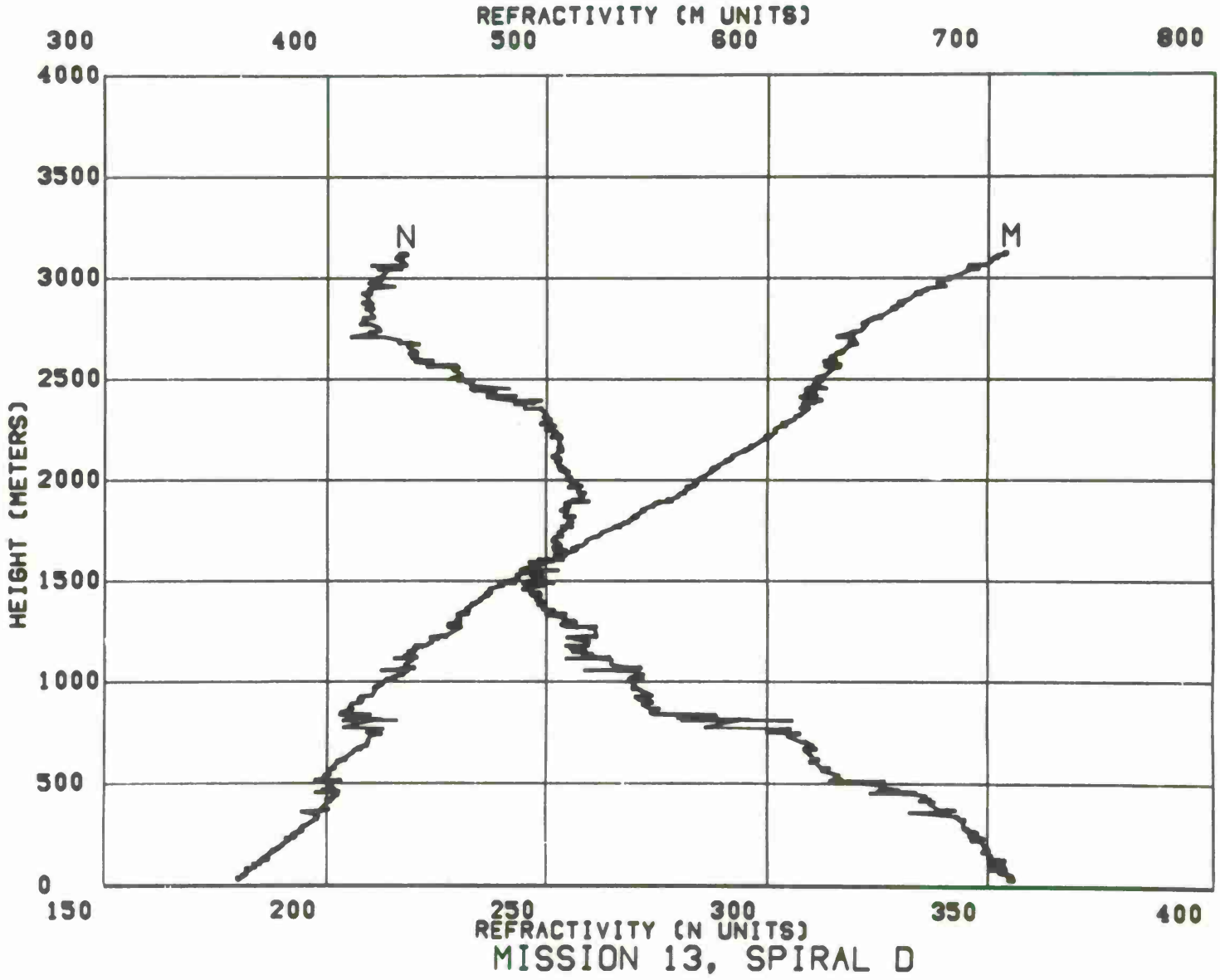
KILOMETERS

FLIGHT PATH VIII

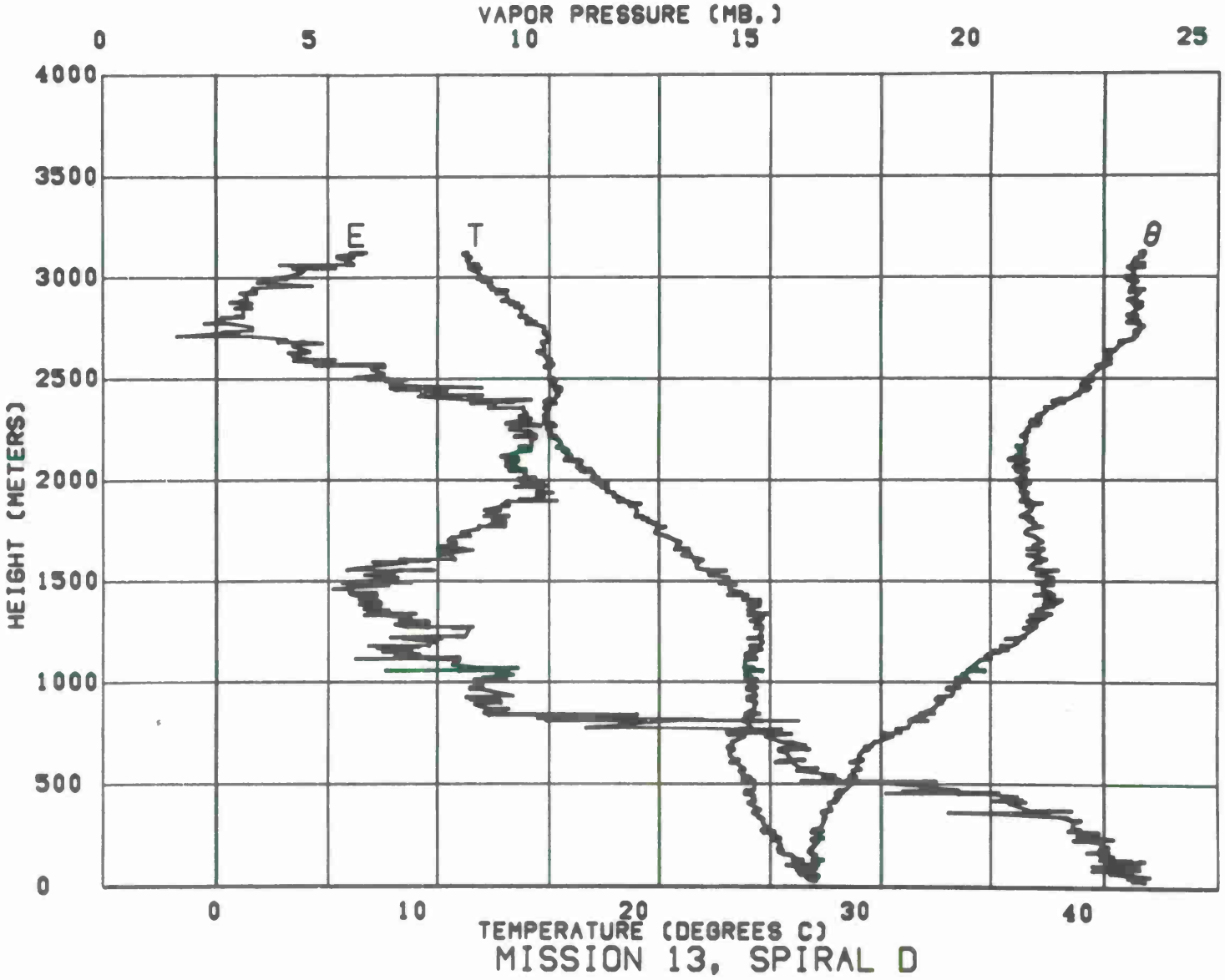
MISSION 12 — 23 MARCH 1969

MISSION 13 — 24 MARCH 1969

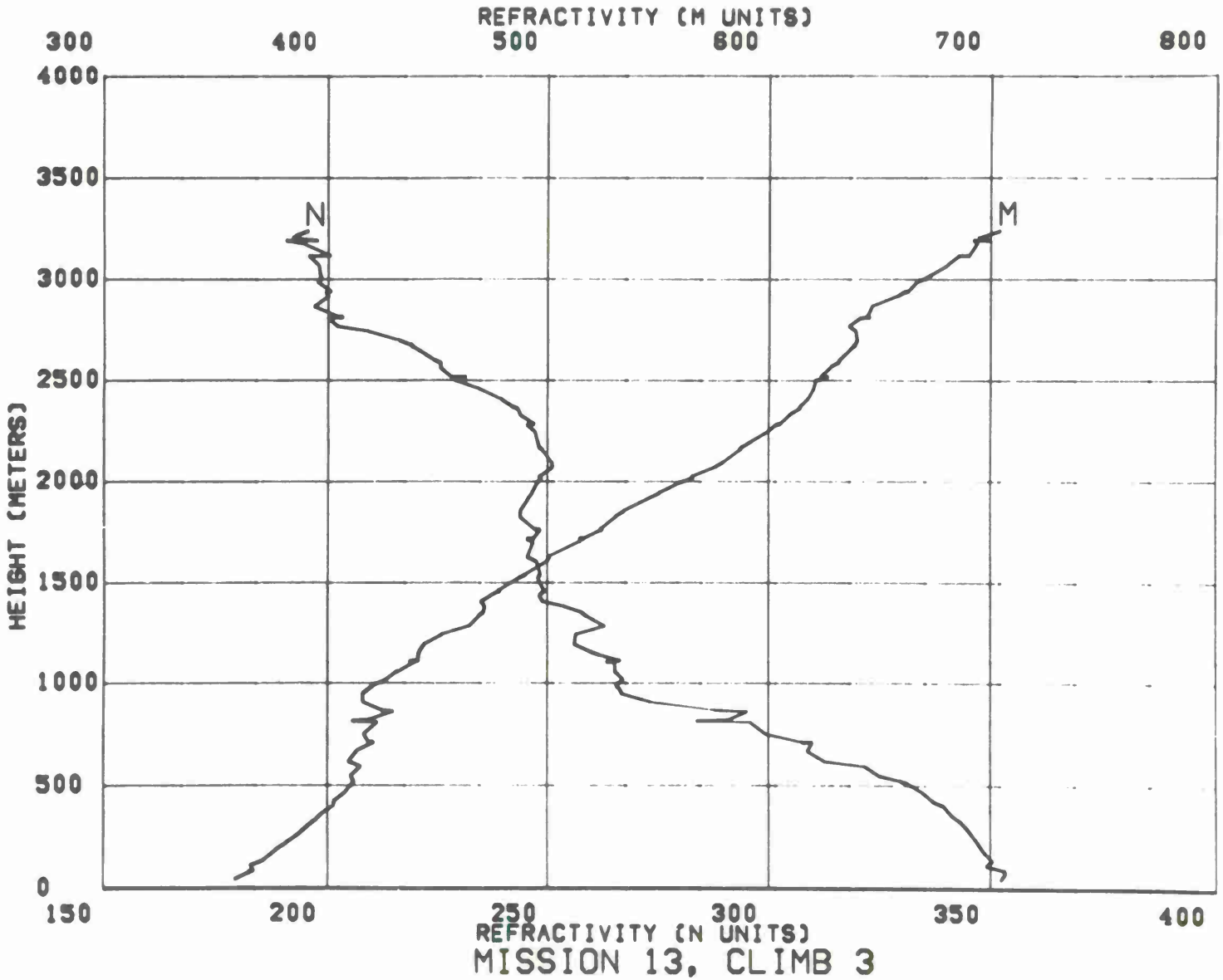
MISSION 14 — 25 MARCH 1969



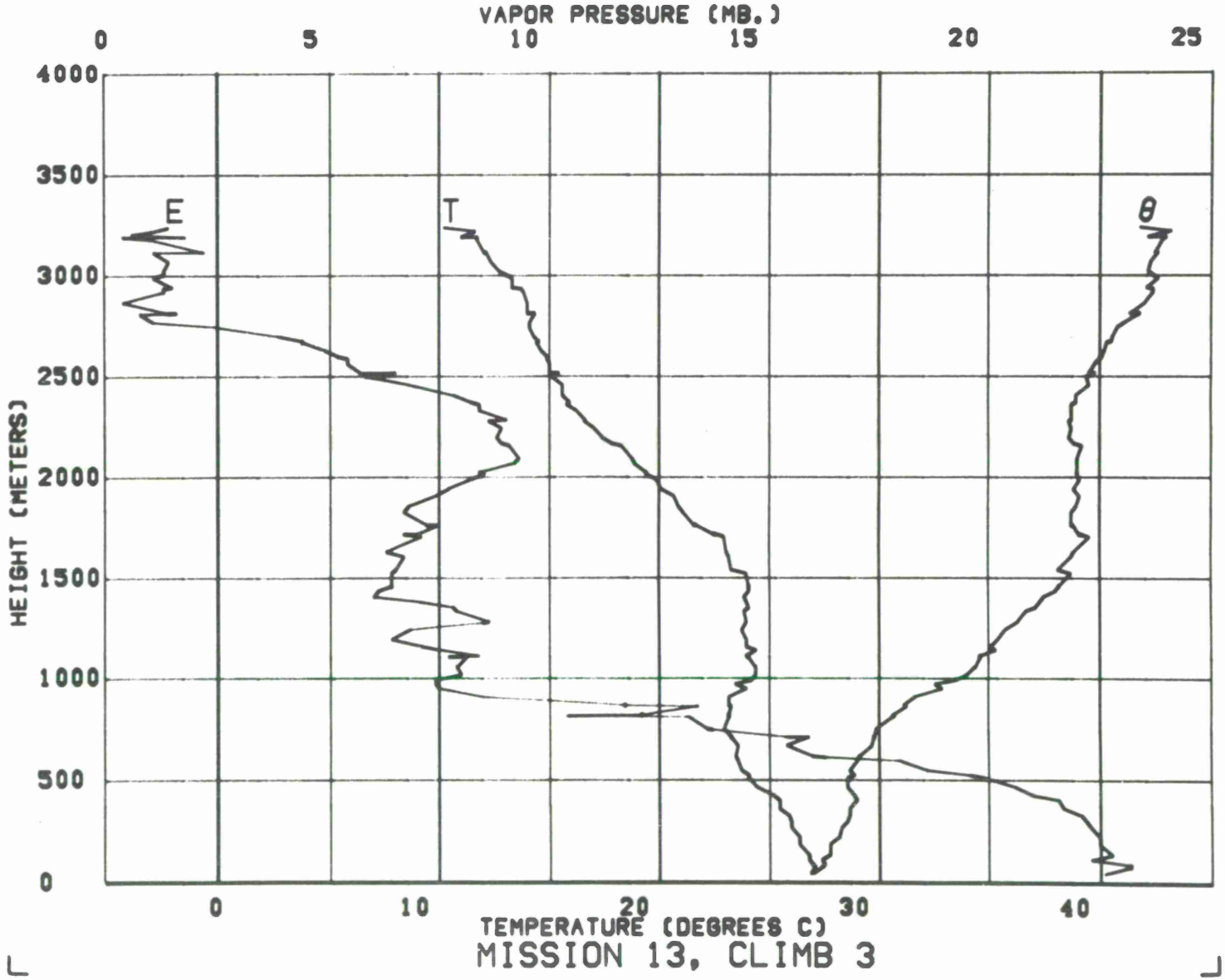
MISSION 13, SPIRAL D

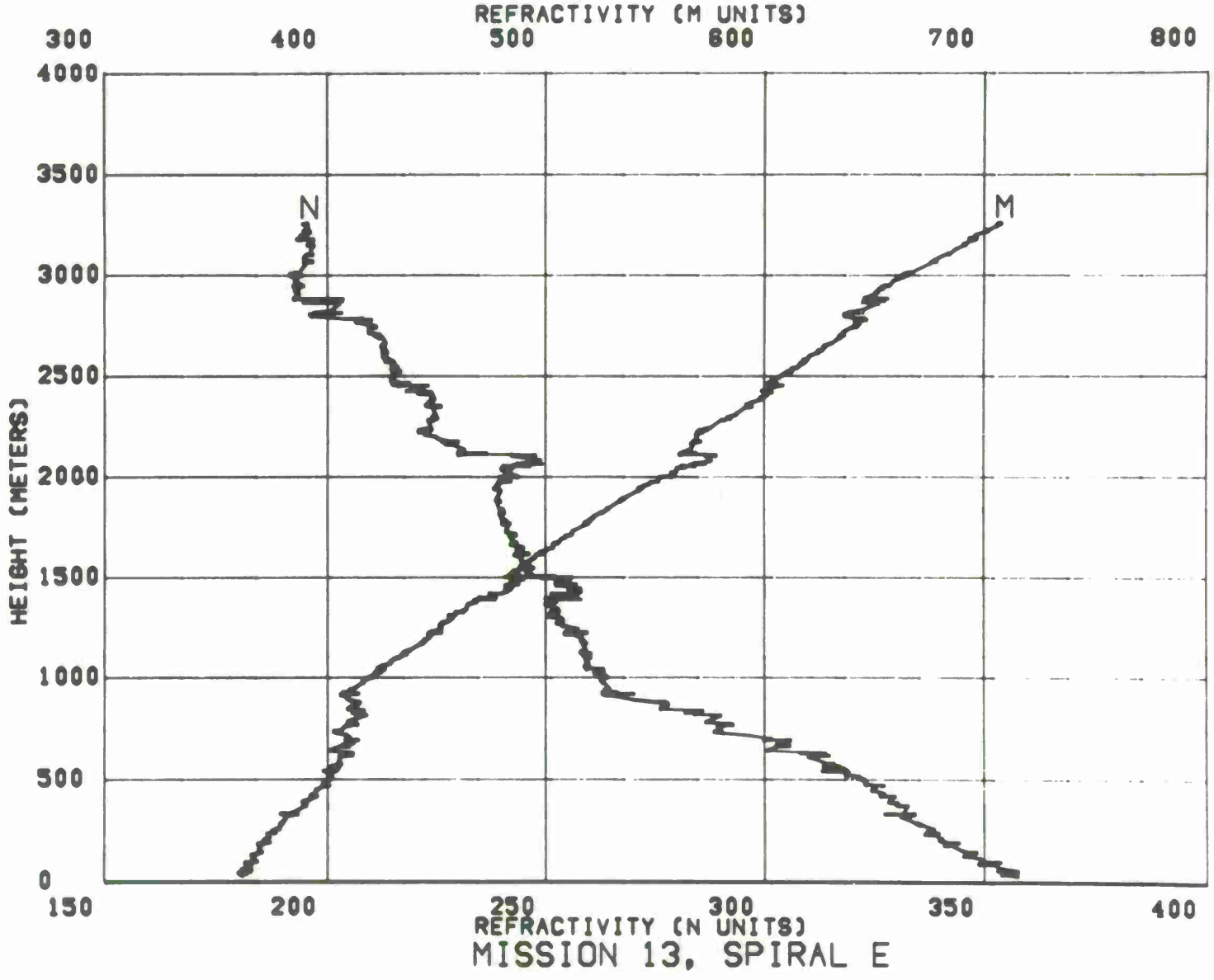


MISSION 13, SPIRAL D

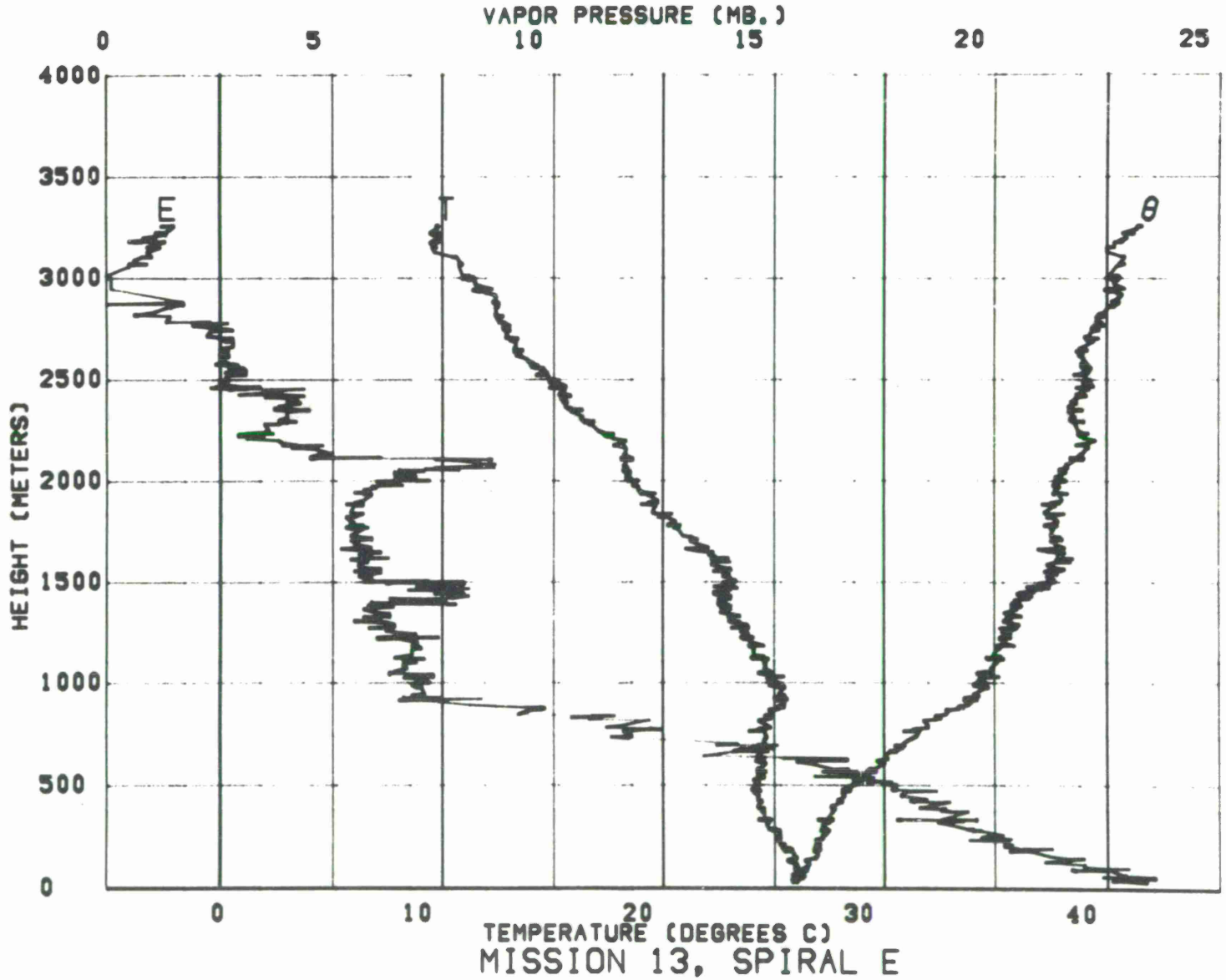


MISSION 13, CLIMB 3

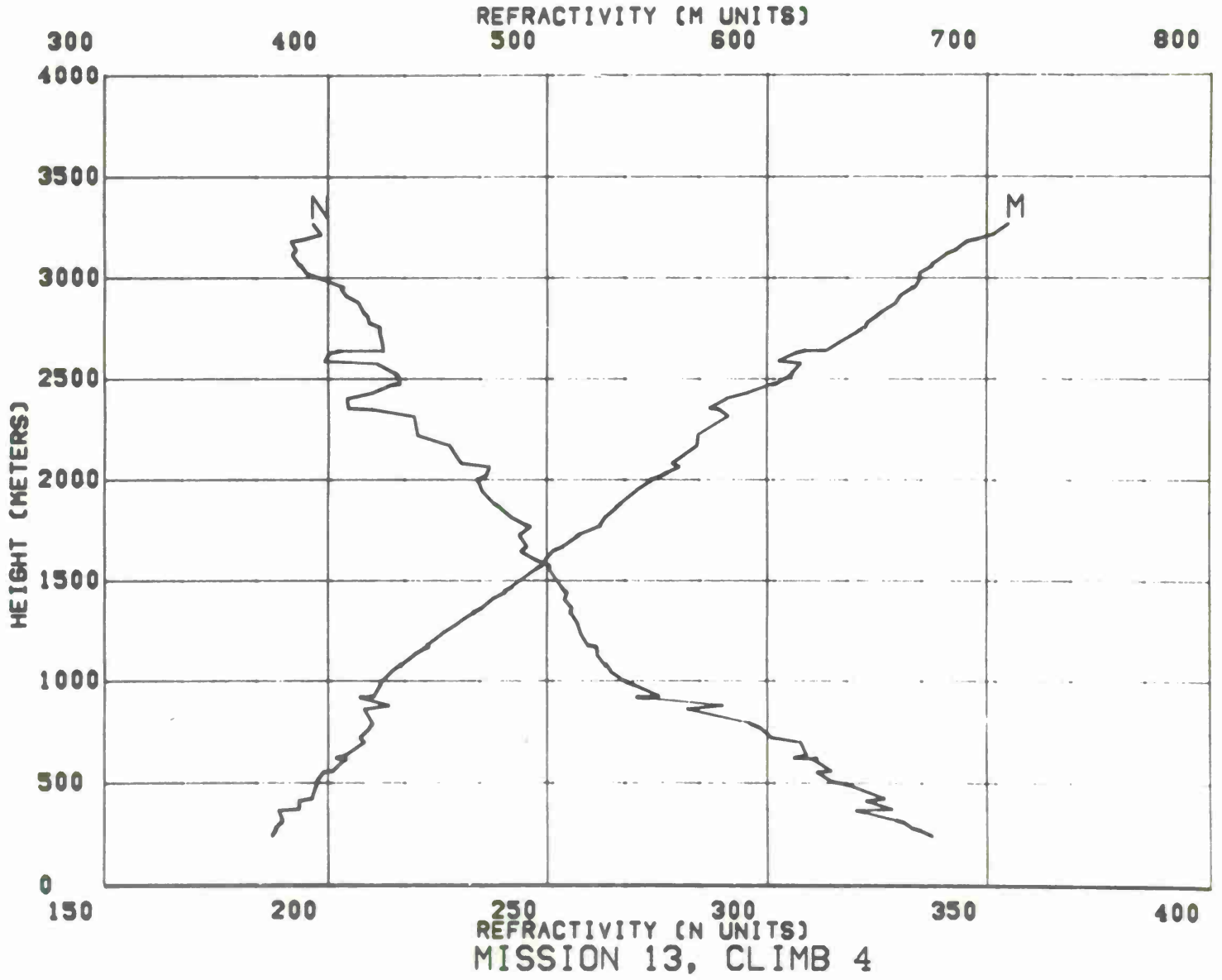

VAPOR PRESSURE (MB.)
0
5
10
15
20
25
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
E
T
θ
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 13, CLIMB 3



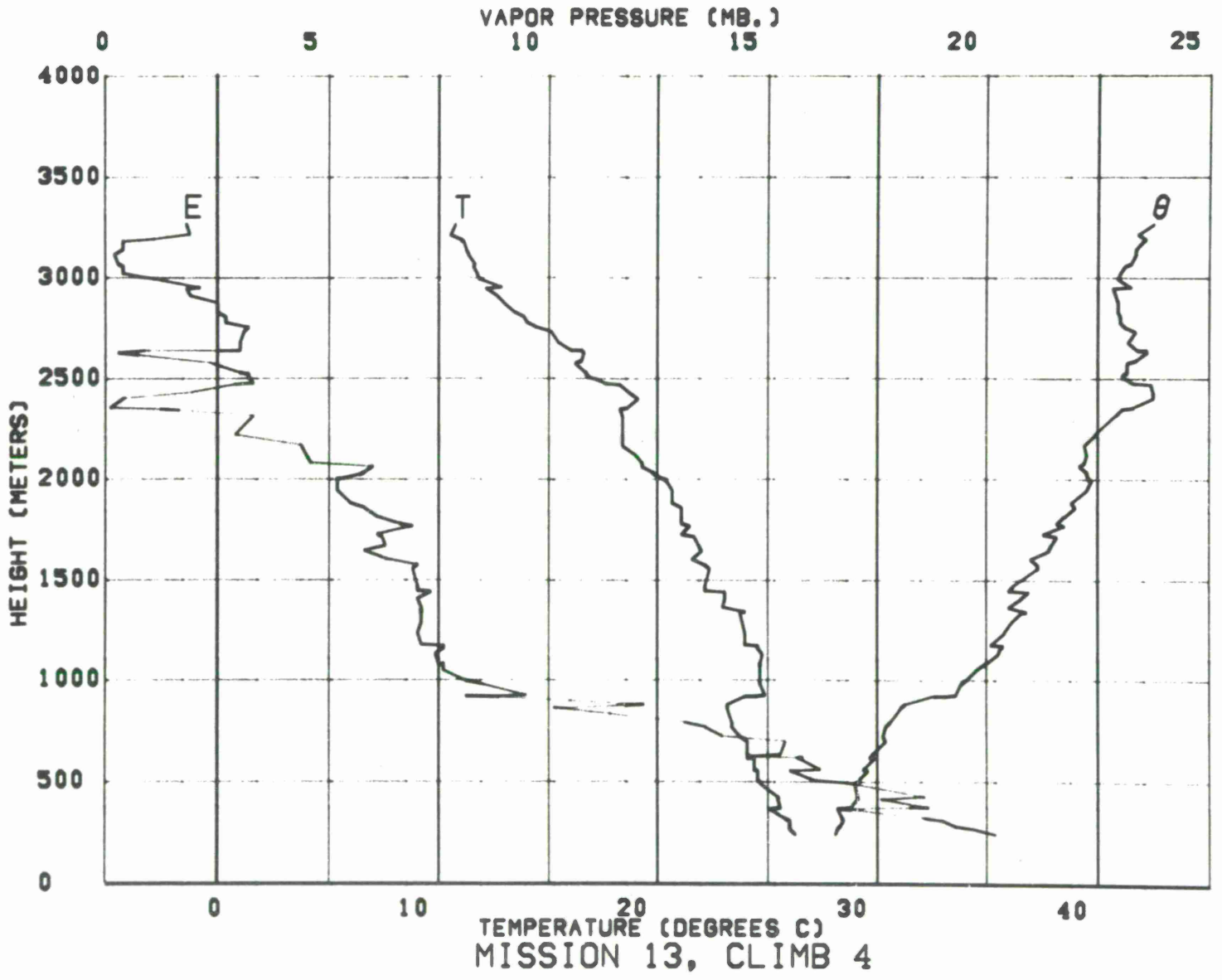
MISSION 13, SPIRAL E



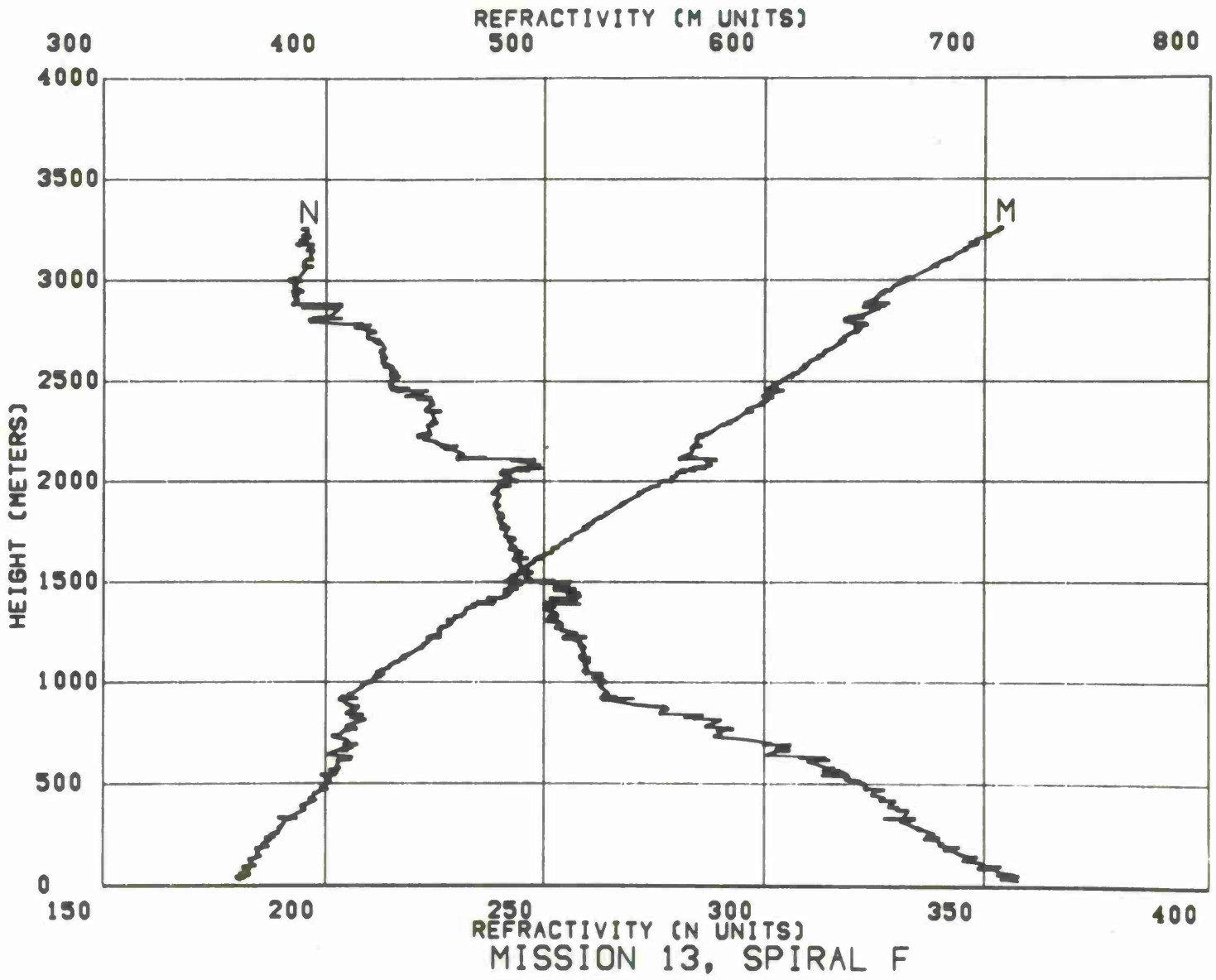
MISSION 13, SPIRAL E



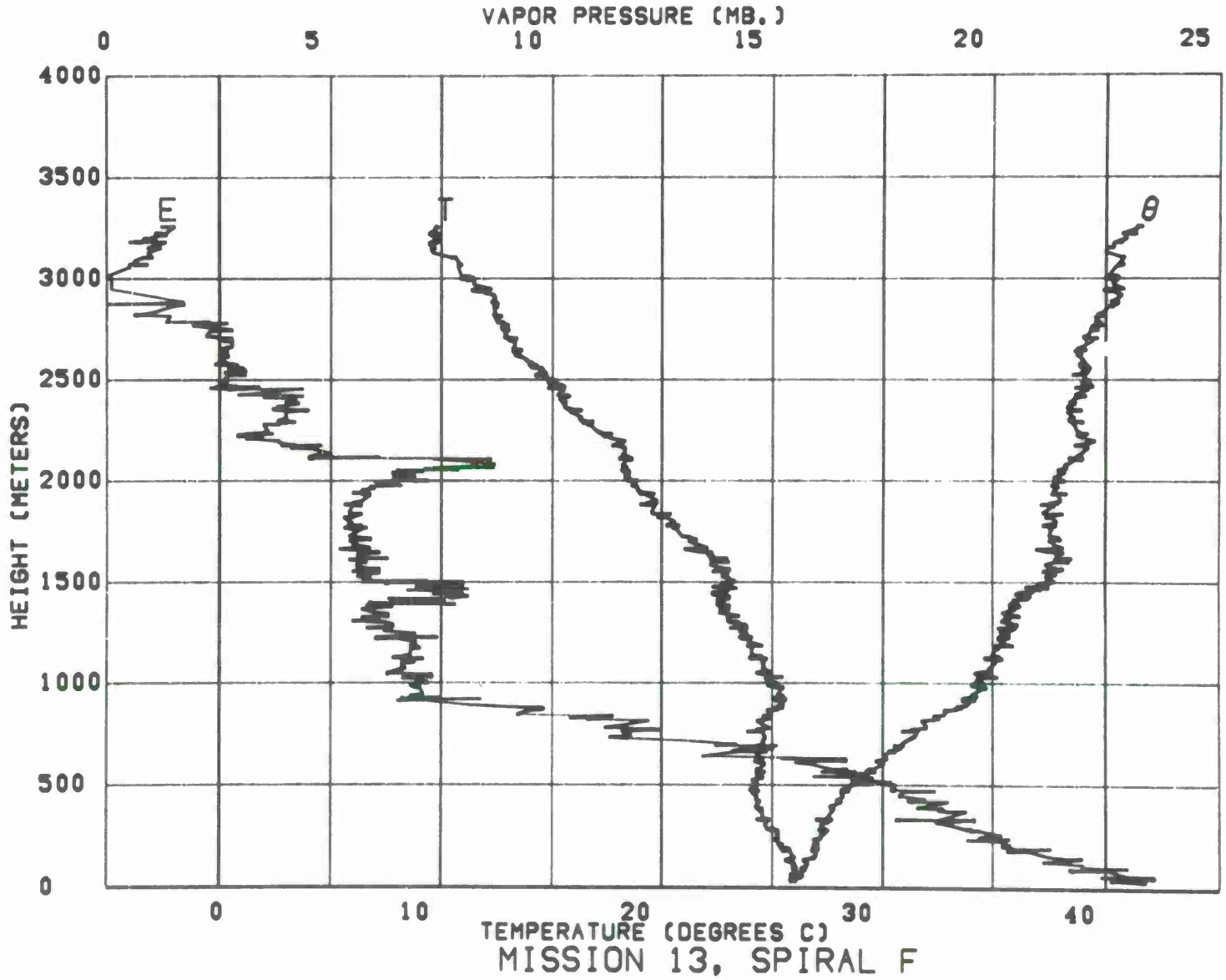
MISSION 13, CLIMB 4



MISSION 13, CLIMB 4



MISSION 13, SPIRAL F



MISSION 13, SPIRAL F

MISSION NO. 14

Date: 25 March 1969

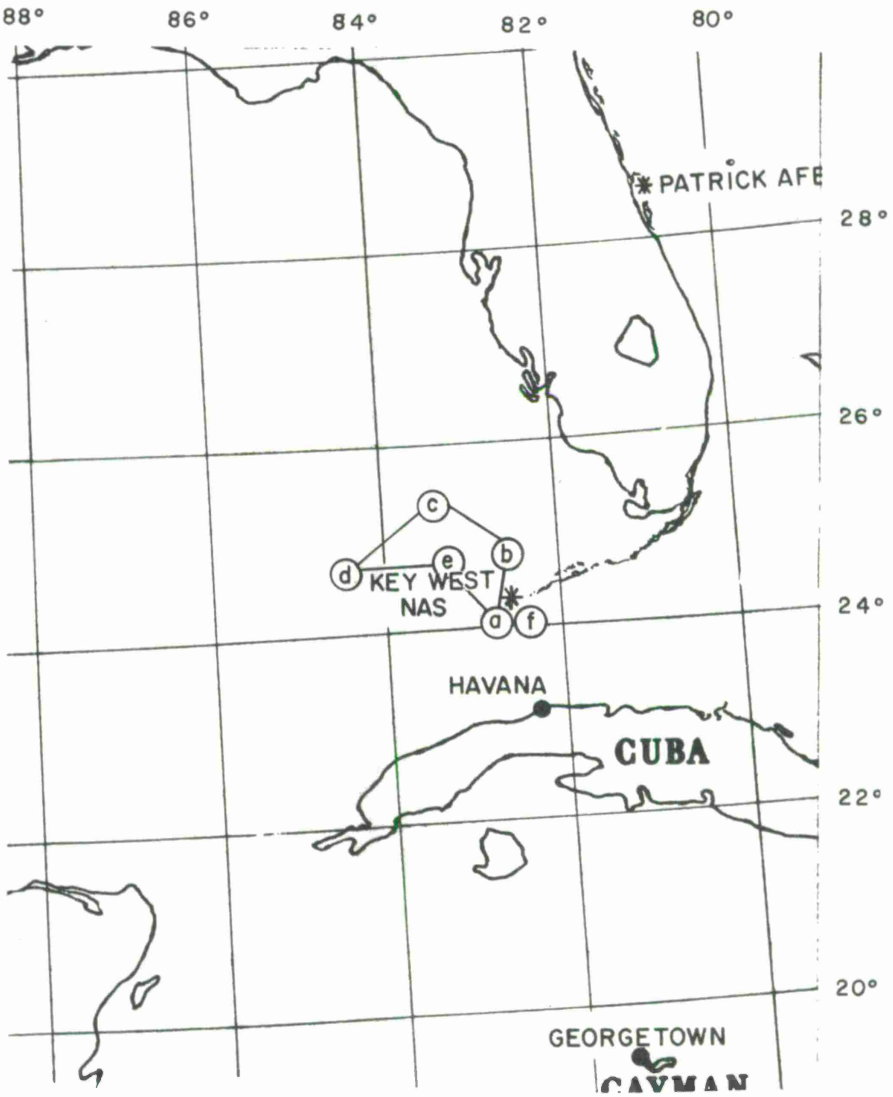
Data were obtained for six spirals and three ascents along Flight Path VIII, westerly from Key West.

The digital data recorded during Climb 2 was affected by an intermittent electronic failure in the analog-to-digital data recorder. Therefore, this section of data could not be processed.

Spiral	Location	Spiral Start Time Z	Local
A	a. Key West	1154	0654
B	b. 24-35 N, 82-37 W	1238	0738
Climb 1	b-c	1257	0757
C	c. 24-35 N, 83-32 W	1320	0820
Climb 2	c-d	1343	0843 (no data)
D	d. 24-35 N, 84-26 W	1403	0903
Climb 3	d-e	1421	0921
E	e. 24-35 N, 83-03 W	1444	0944
Climb 4			
F	a. Key West	1527	1027

NOTE: Spiral C lies in the plane through deb.

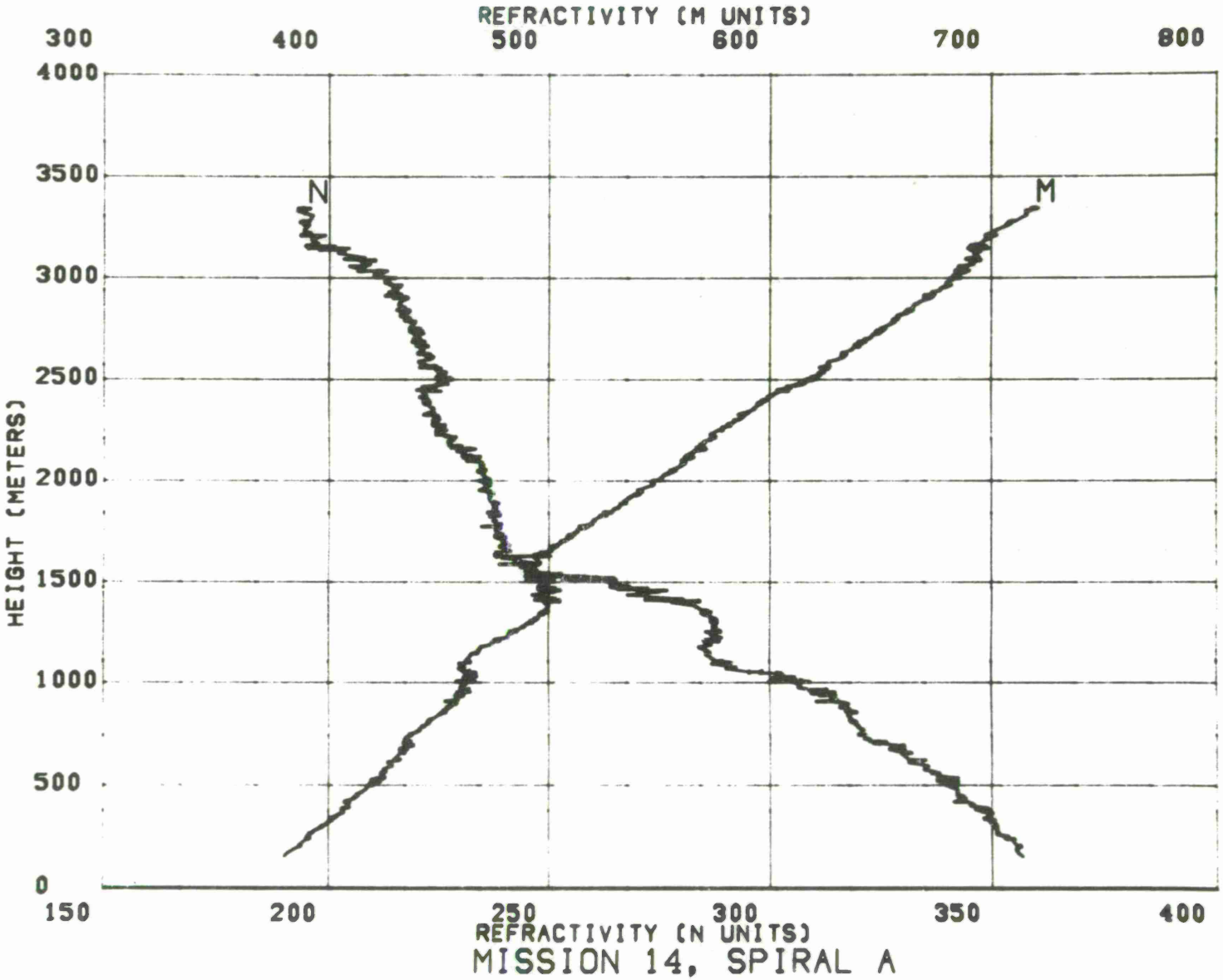
87093



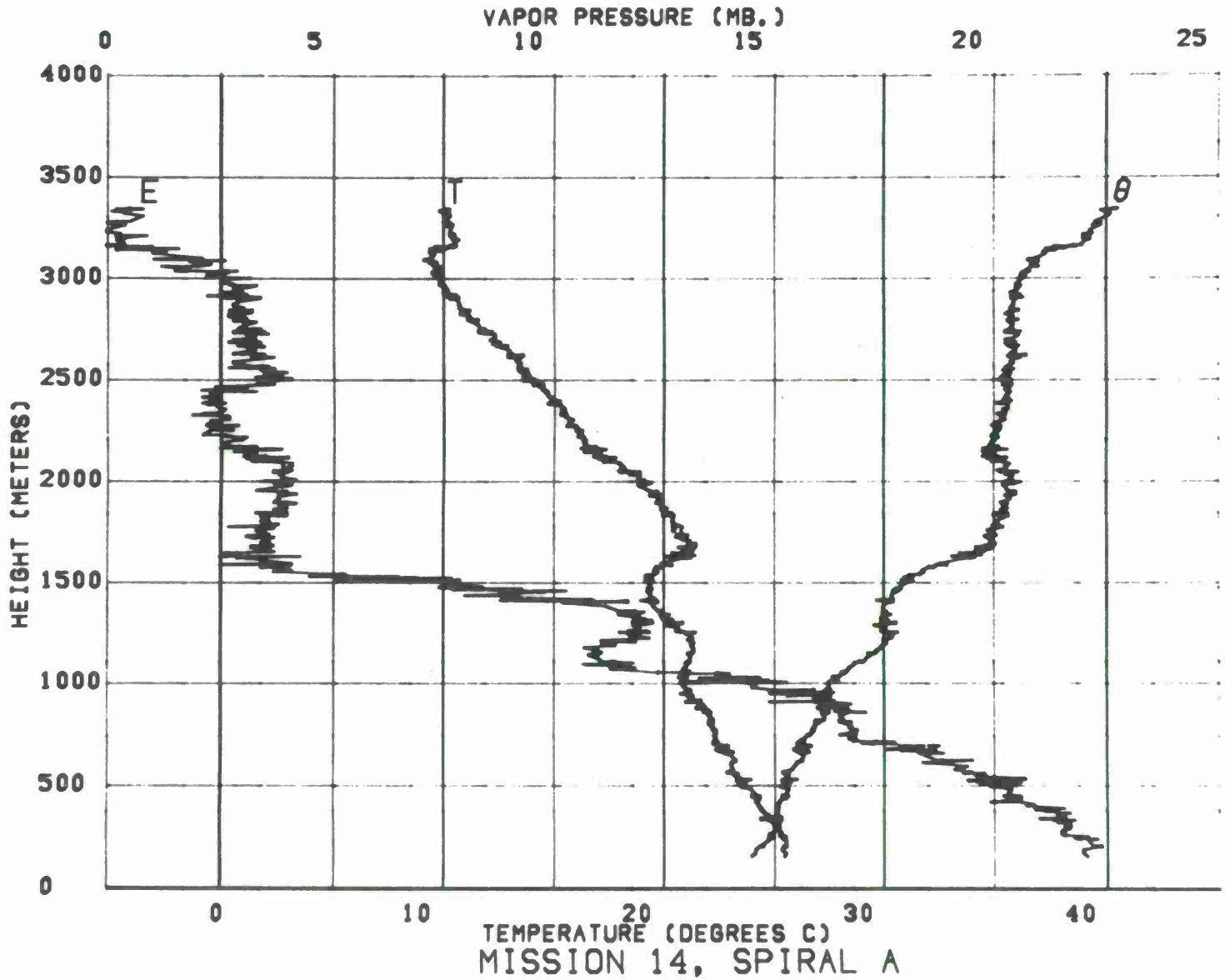
SCALE 1:5,702,400 OR 90 MILES TO 1 INCH

100 50 0 100 200 300
STATUTE MILES
100 50 0 100 200 300 400
KILOMETERS

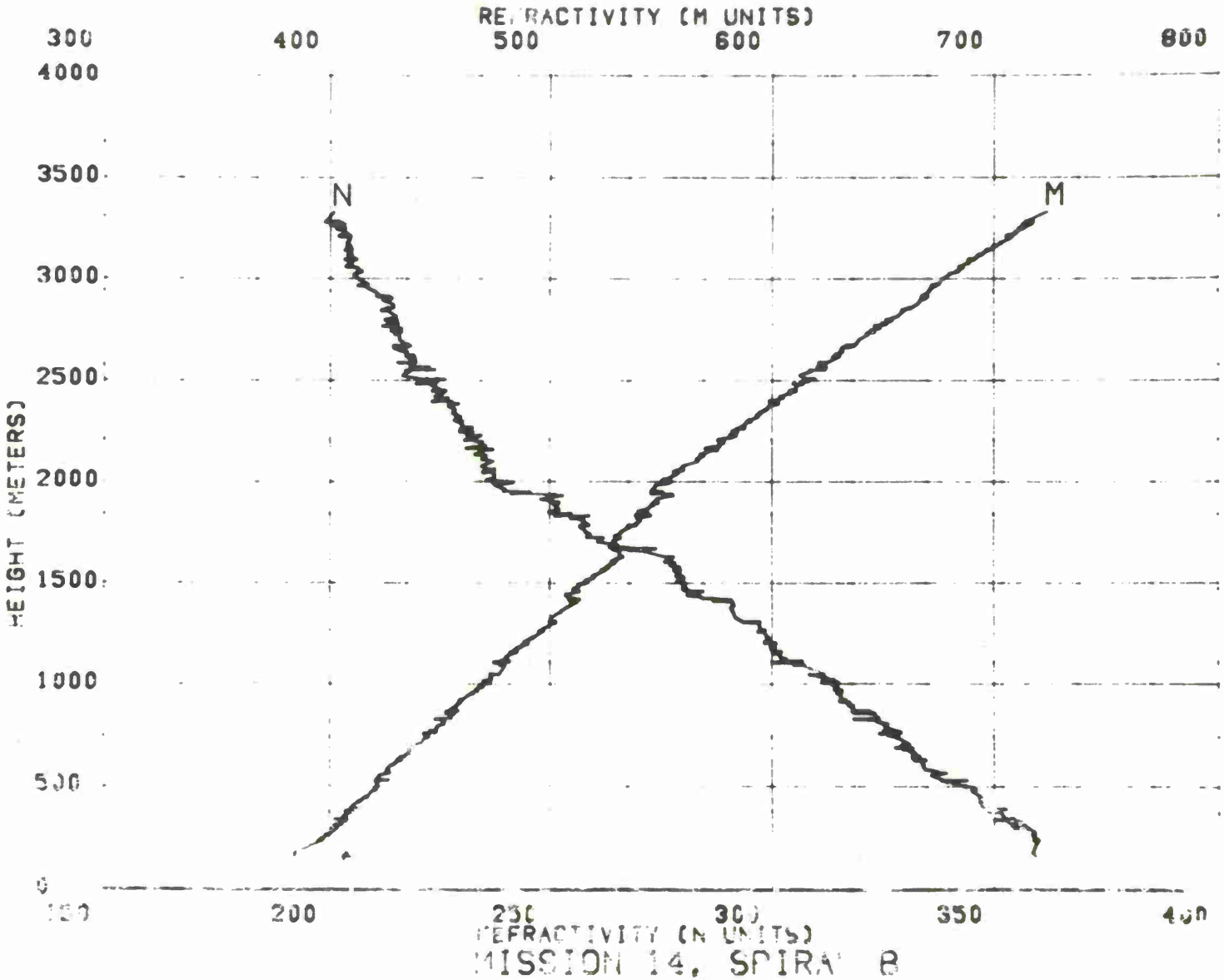
FLIGHT PATH VIII
MISSION 12 — 23 MARCH 1969
MISSION 13 — 24 MARCH 1969
MISSION 14 — 25 MARCH 1969

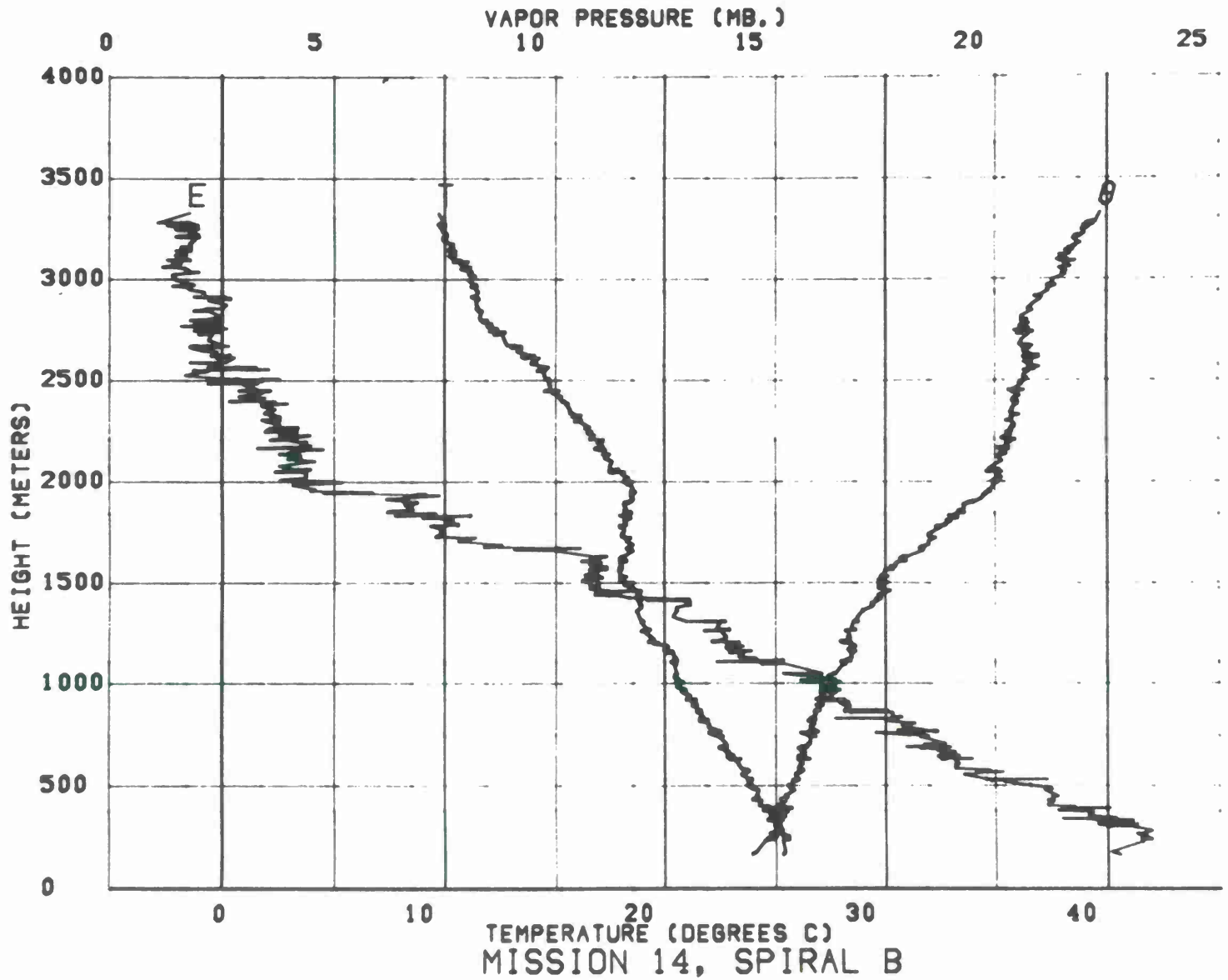


MISSION 14, SPIRAL A

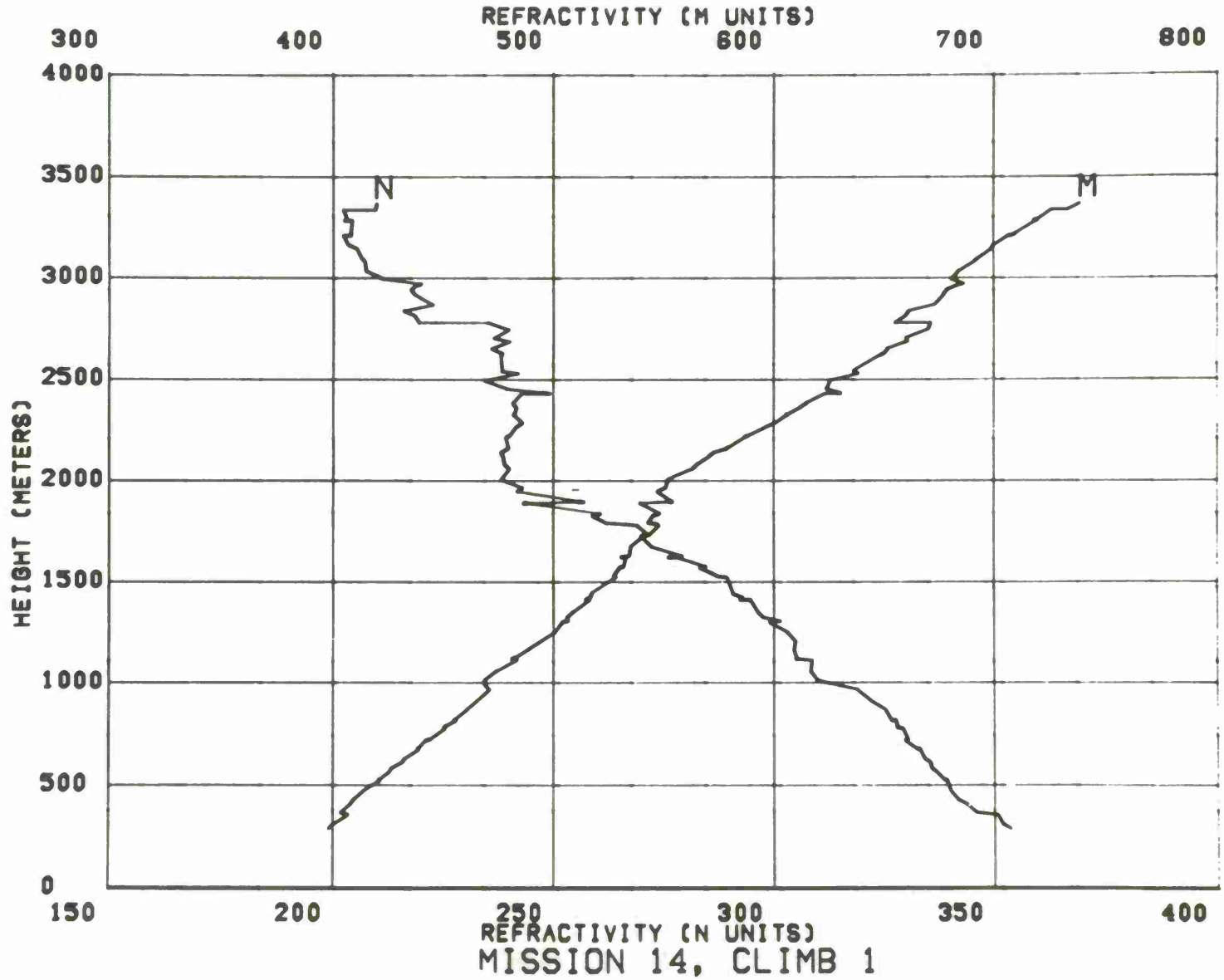


MISSION 14, SPIRAL A

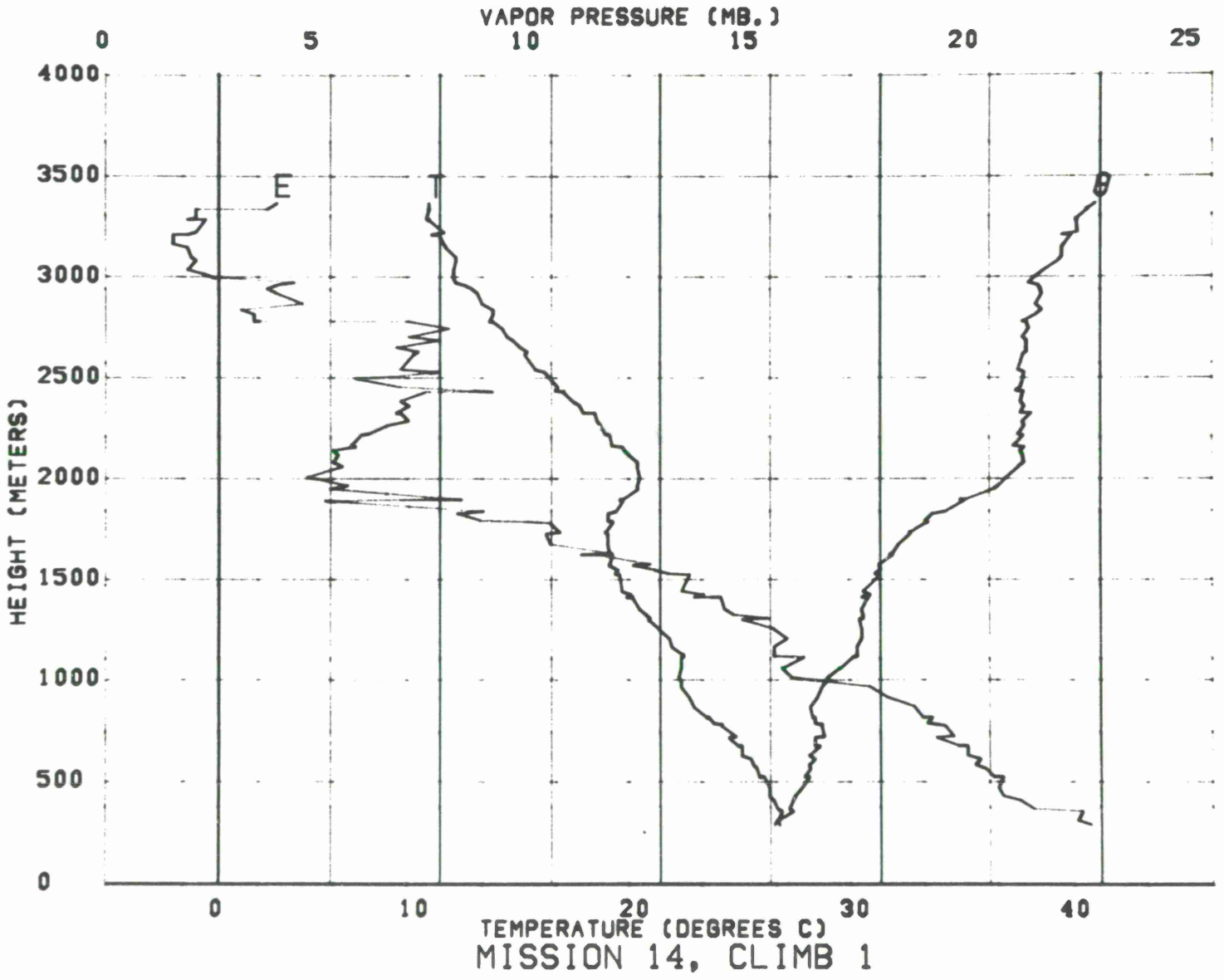

REFRACTIVITY (M UNITS)
300
400
500
600
700
800
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
N
M
200
350
REFRACTIVITY (M UNITS)
MISSION 14, SPIRAL B



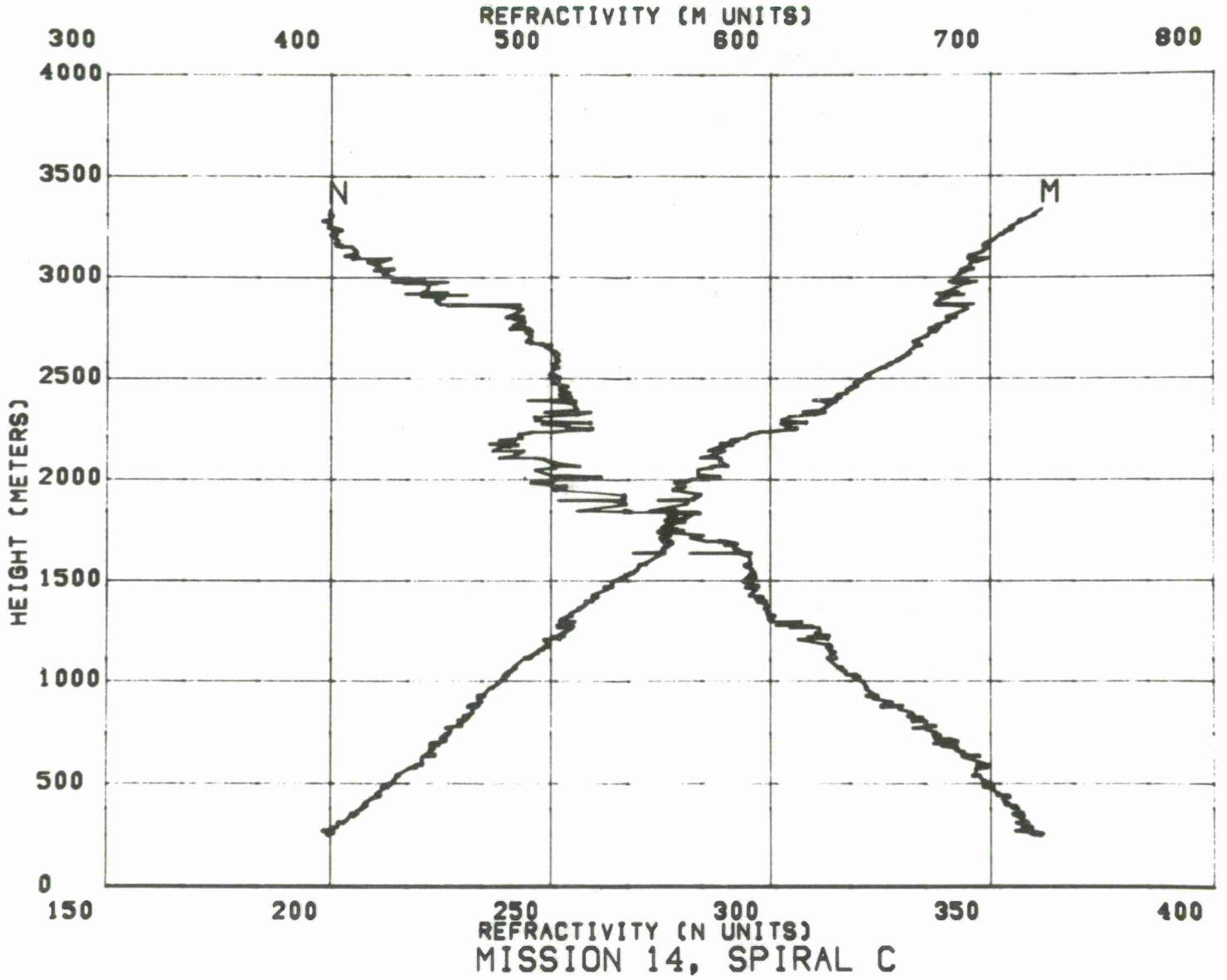
MISSION 14, SPIRAL B



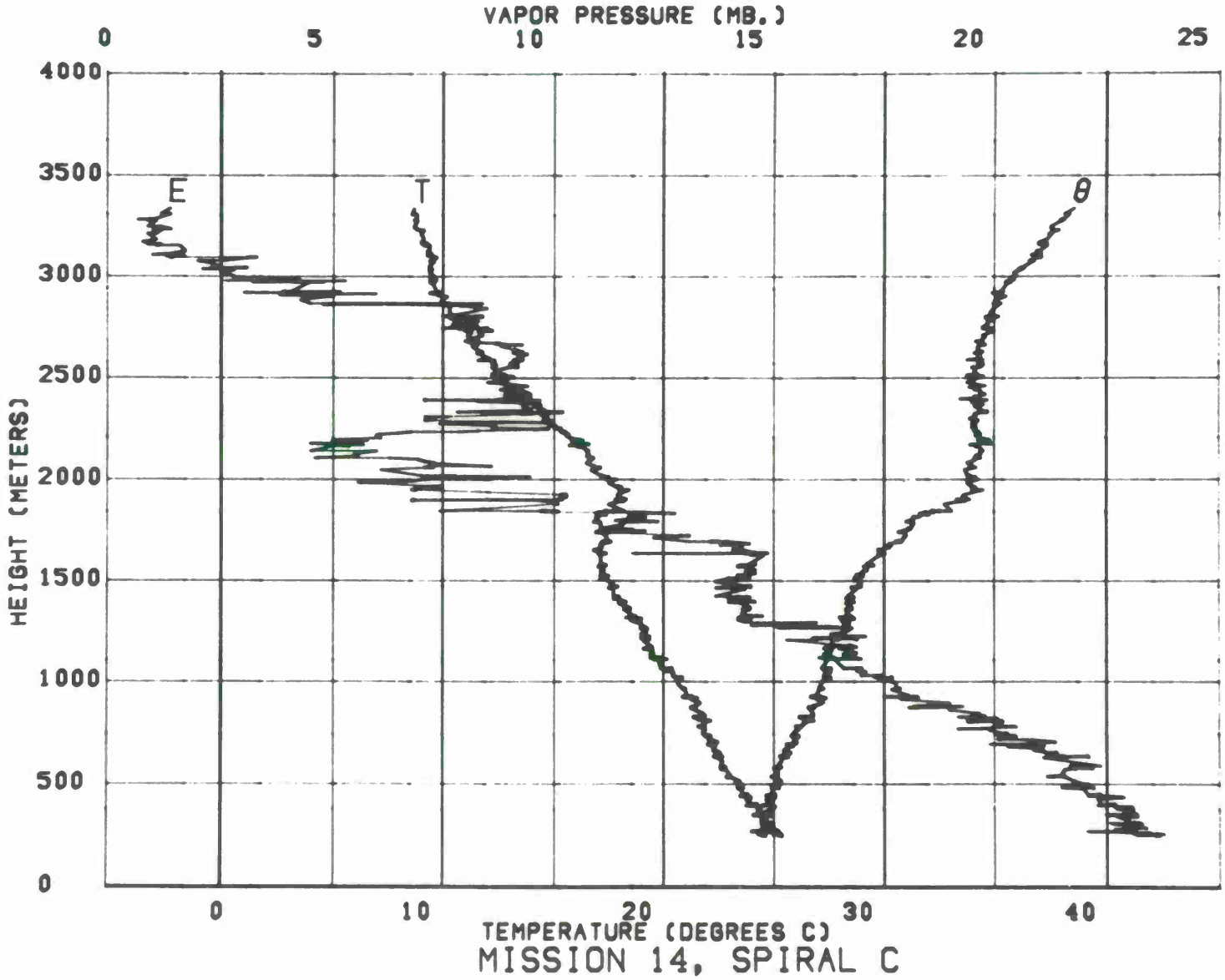
MISSION 14, CLIMB 1



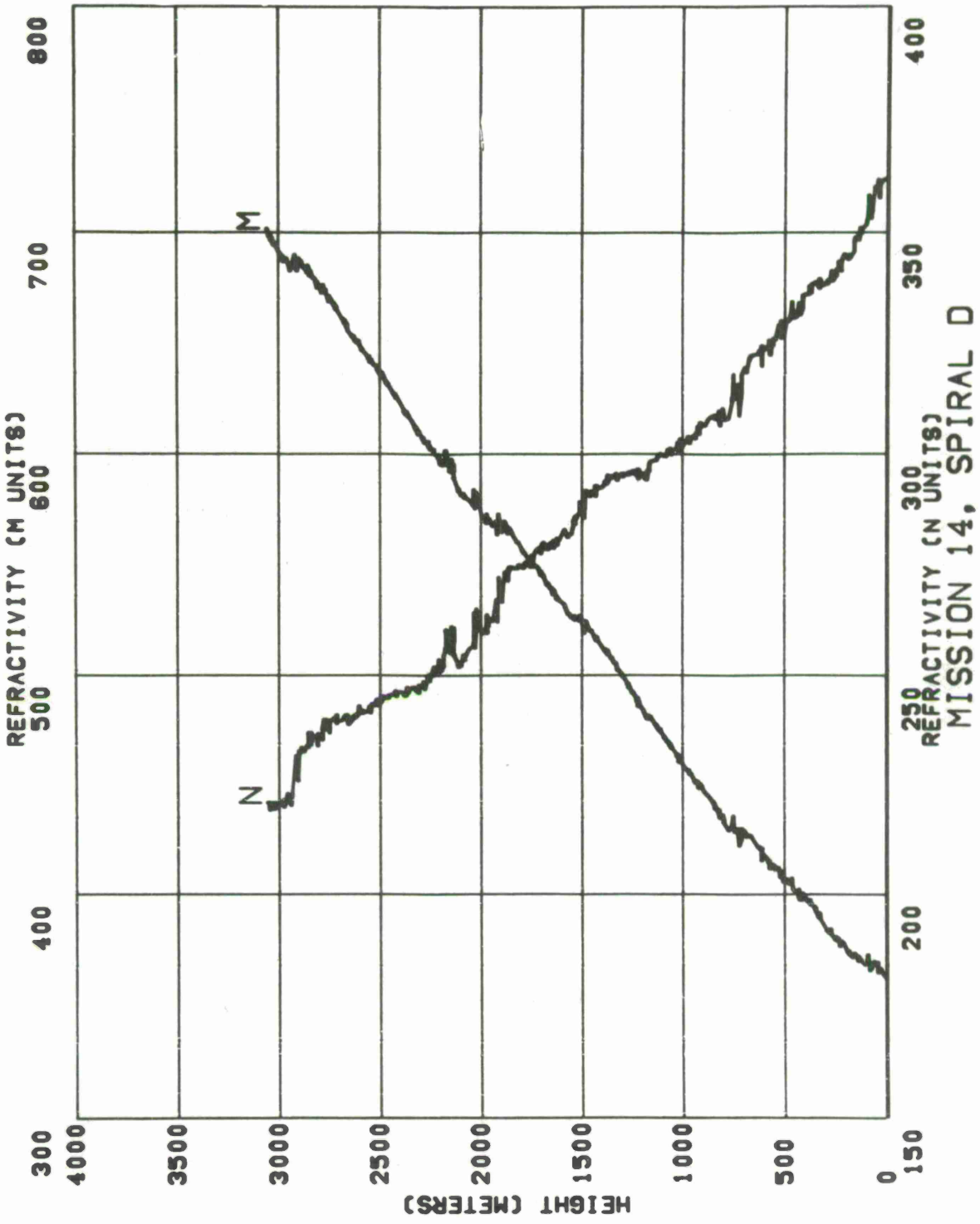
MISSION 14, CLIMB 1

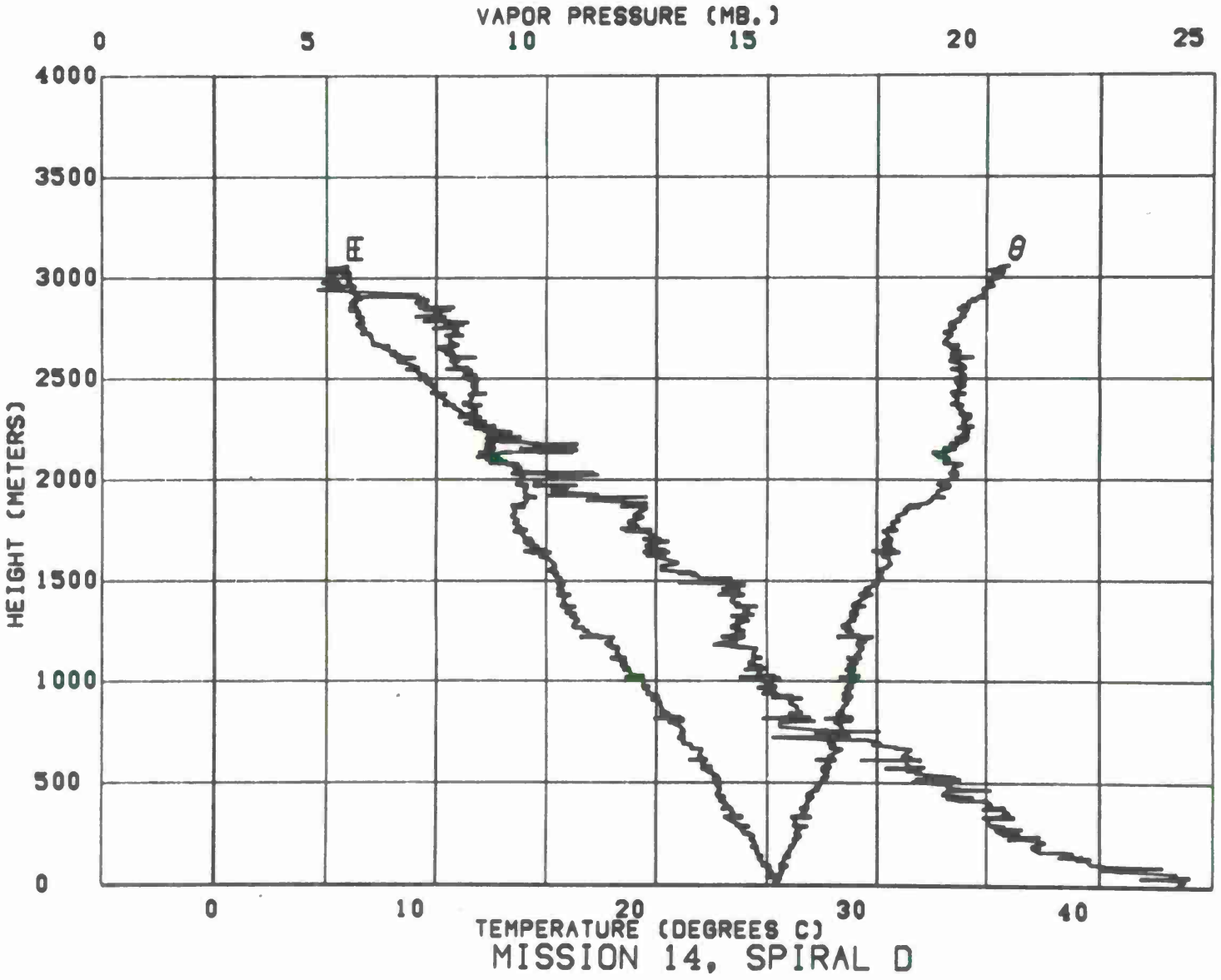


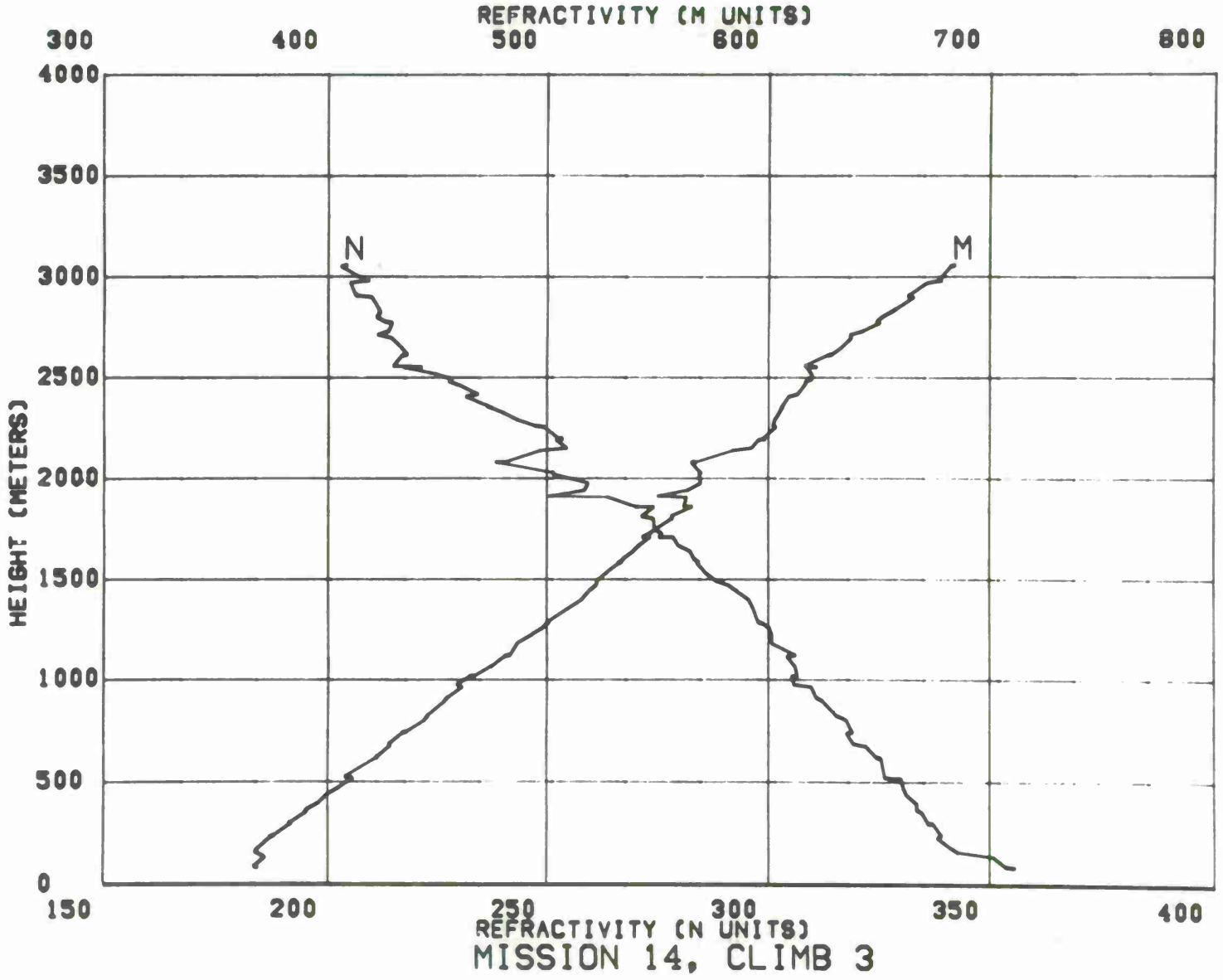
MISSION 14, SPIRAL C



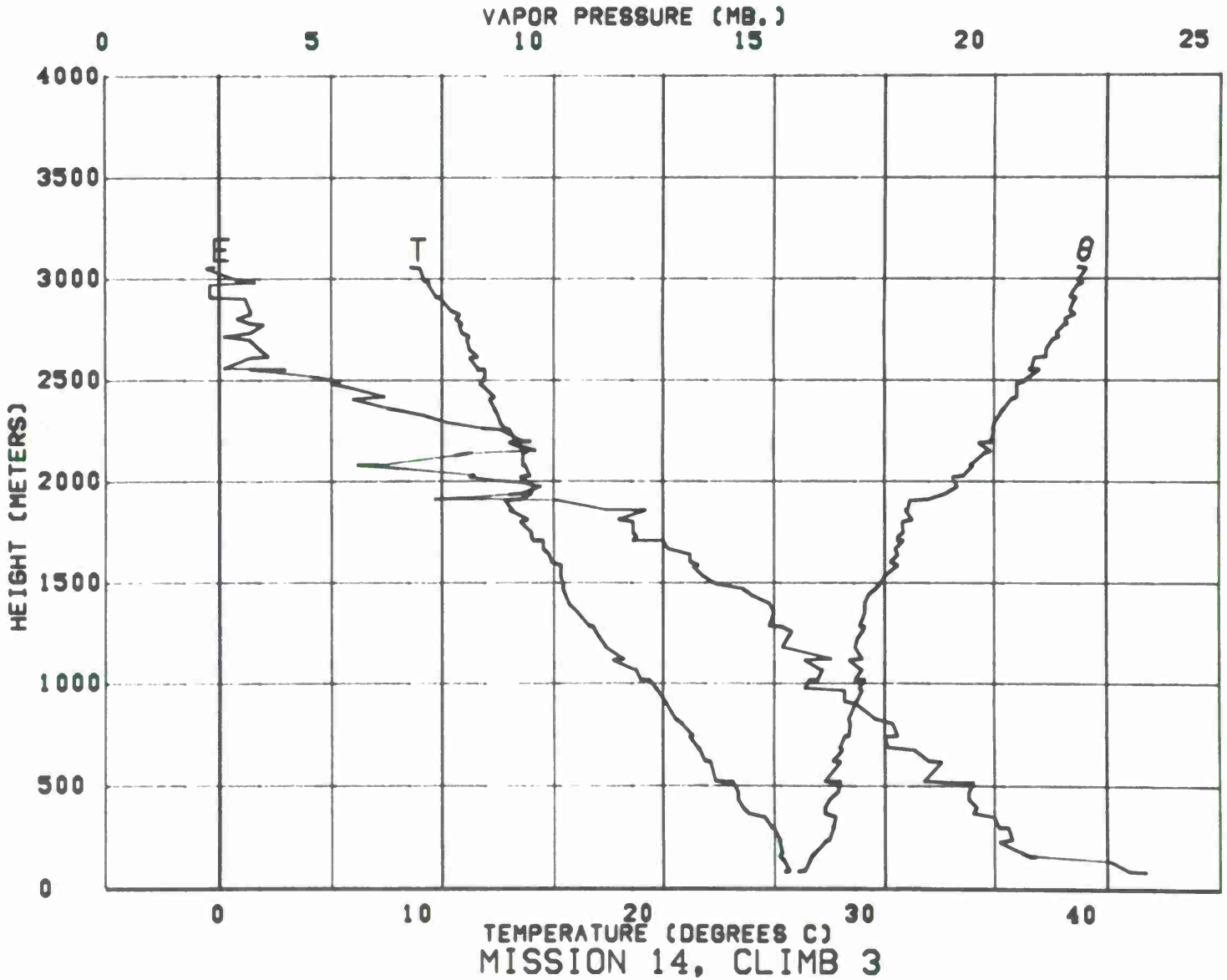
MISSION 14, SPIRAL C


REFRACTIVITY (M UNITS)
300
400
500
600
700
800
HEIGHT (METERS)
4000
3500
3000
2500
2000
1500
1000
500
0
M
N
REFRACTIVITY (N UNITS)
150
200
250
300
350
400
MISSION 14, SPIRAL D

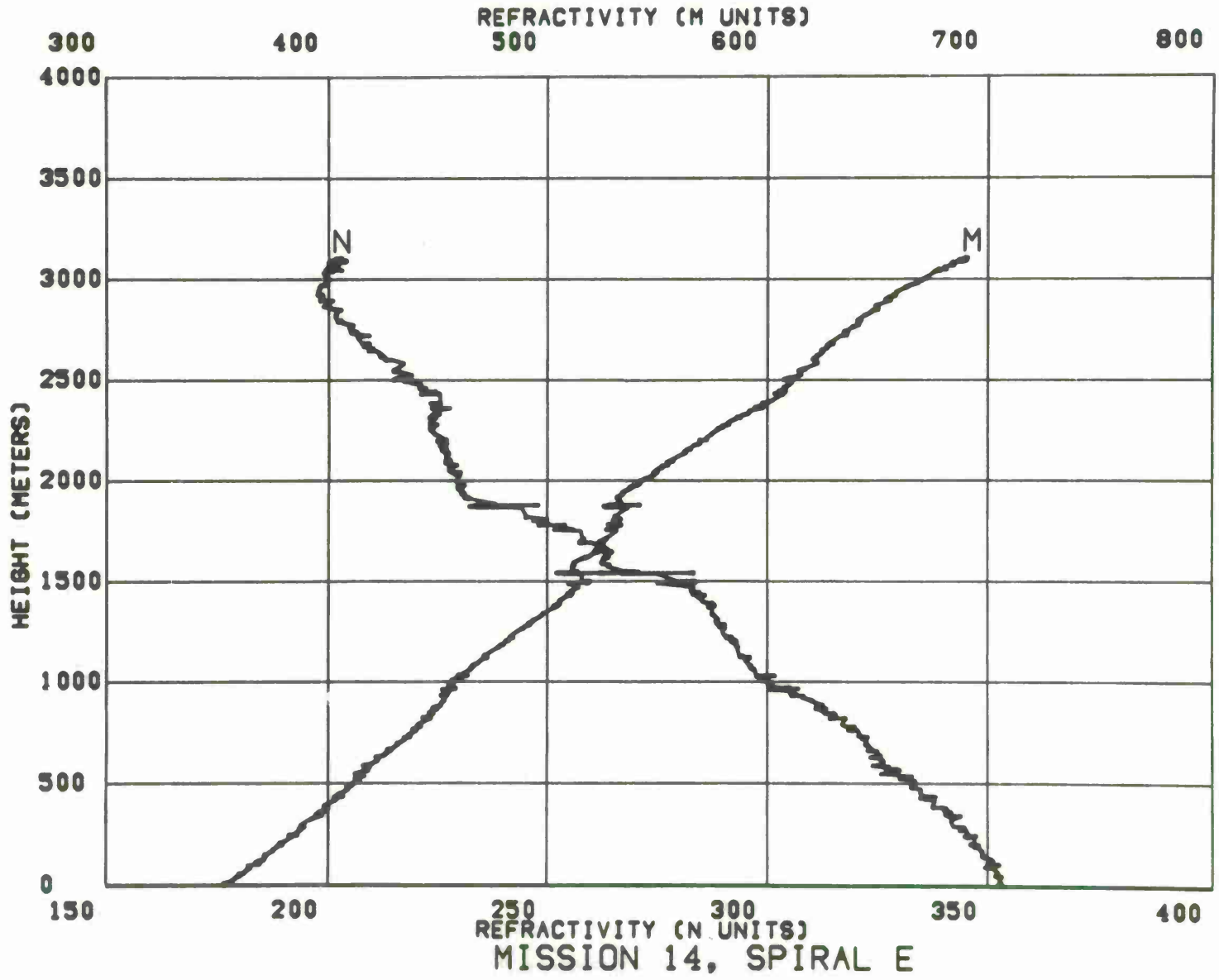

VAPOR PRESSURE (MB.)
0
5
10
15
20
25
4000
3500
3000
2500
2000
1500
1000
500
0
HEIGHT (METERS)
0
10
20
30
40
TEMPERATURE (DEGREES C)
MISSION 14, SPIRAL D



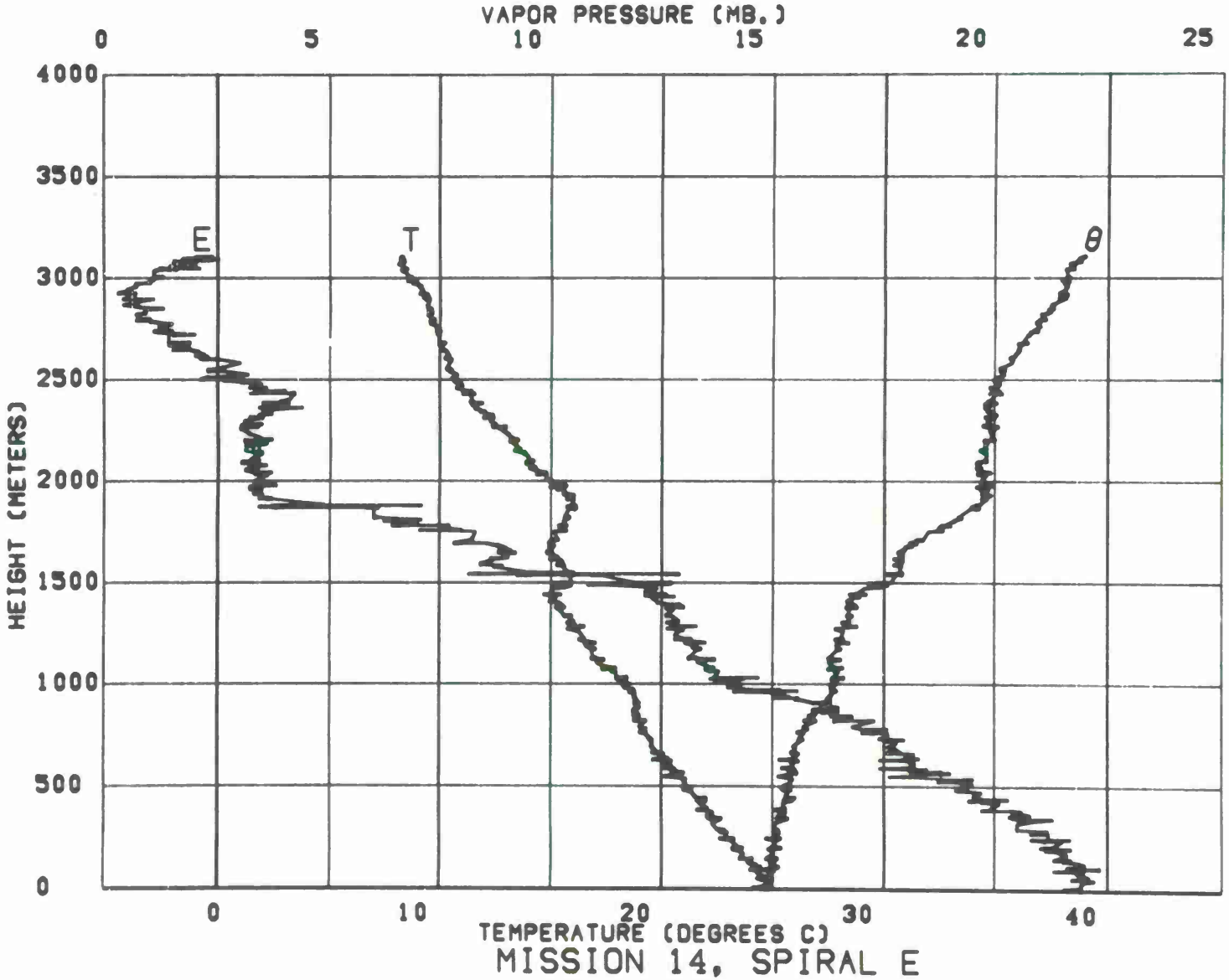
MISSION 14, CLIMB 3



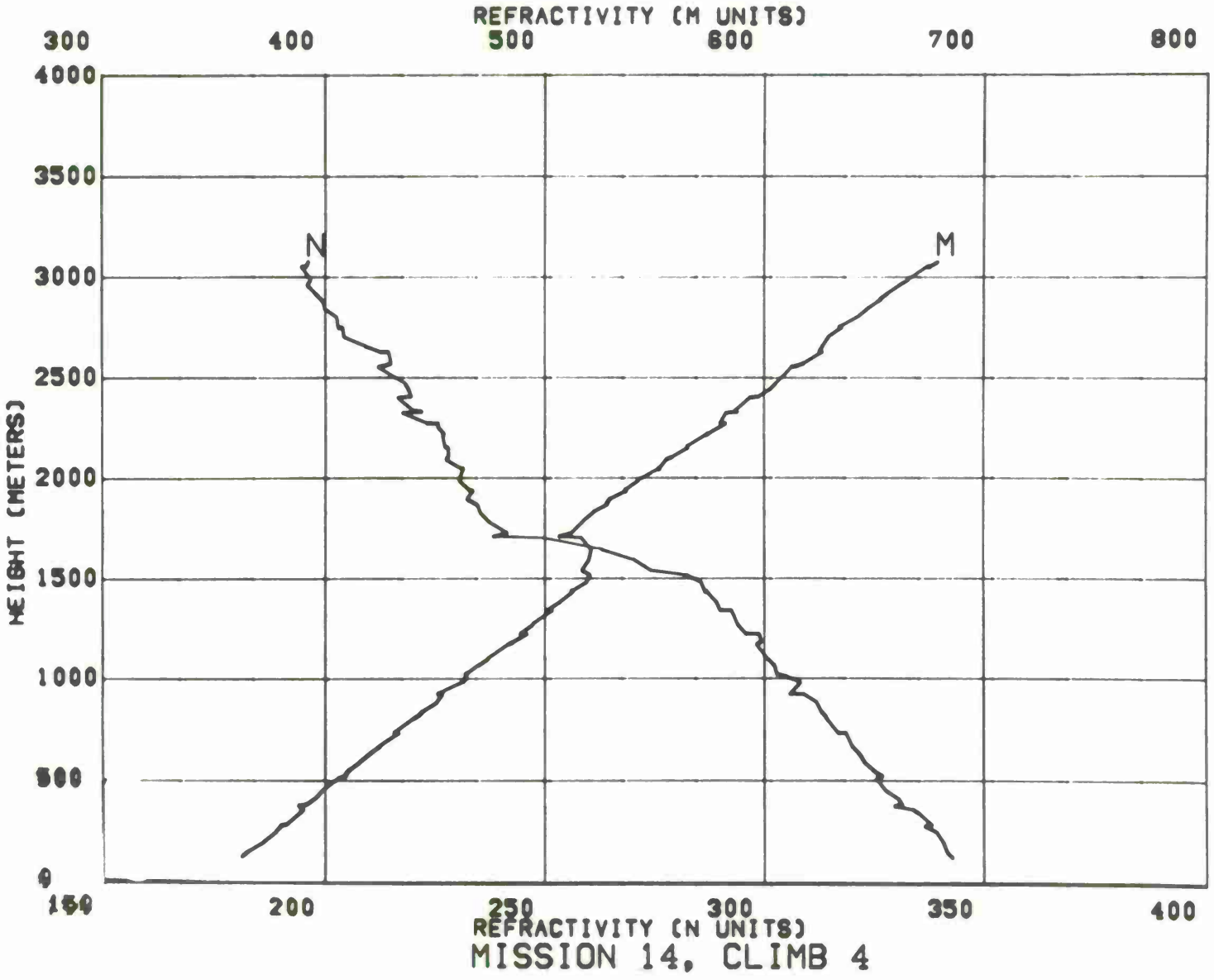
MISSION 14, CLIMB 3



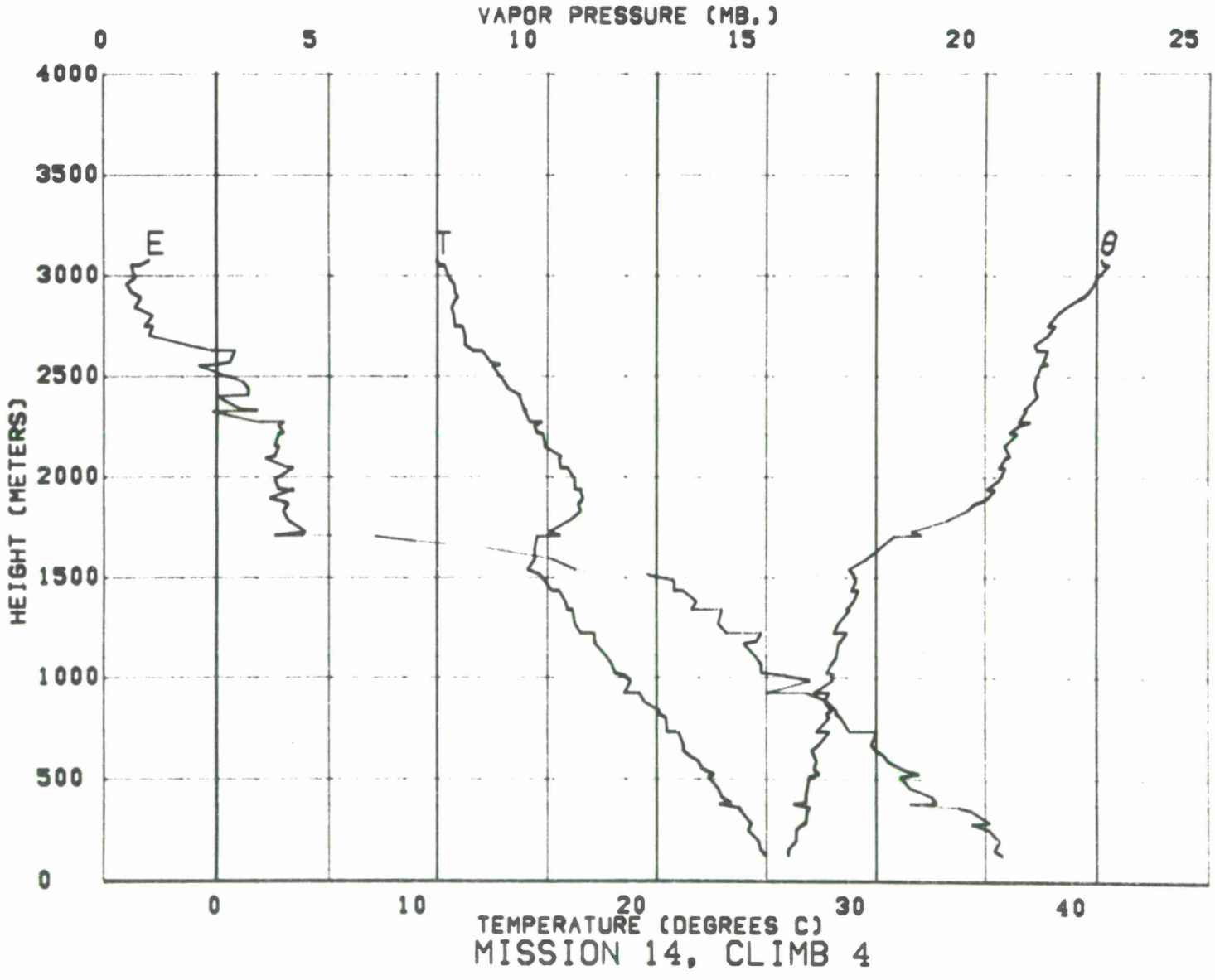
MISSION 14, SPIRAL E



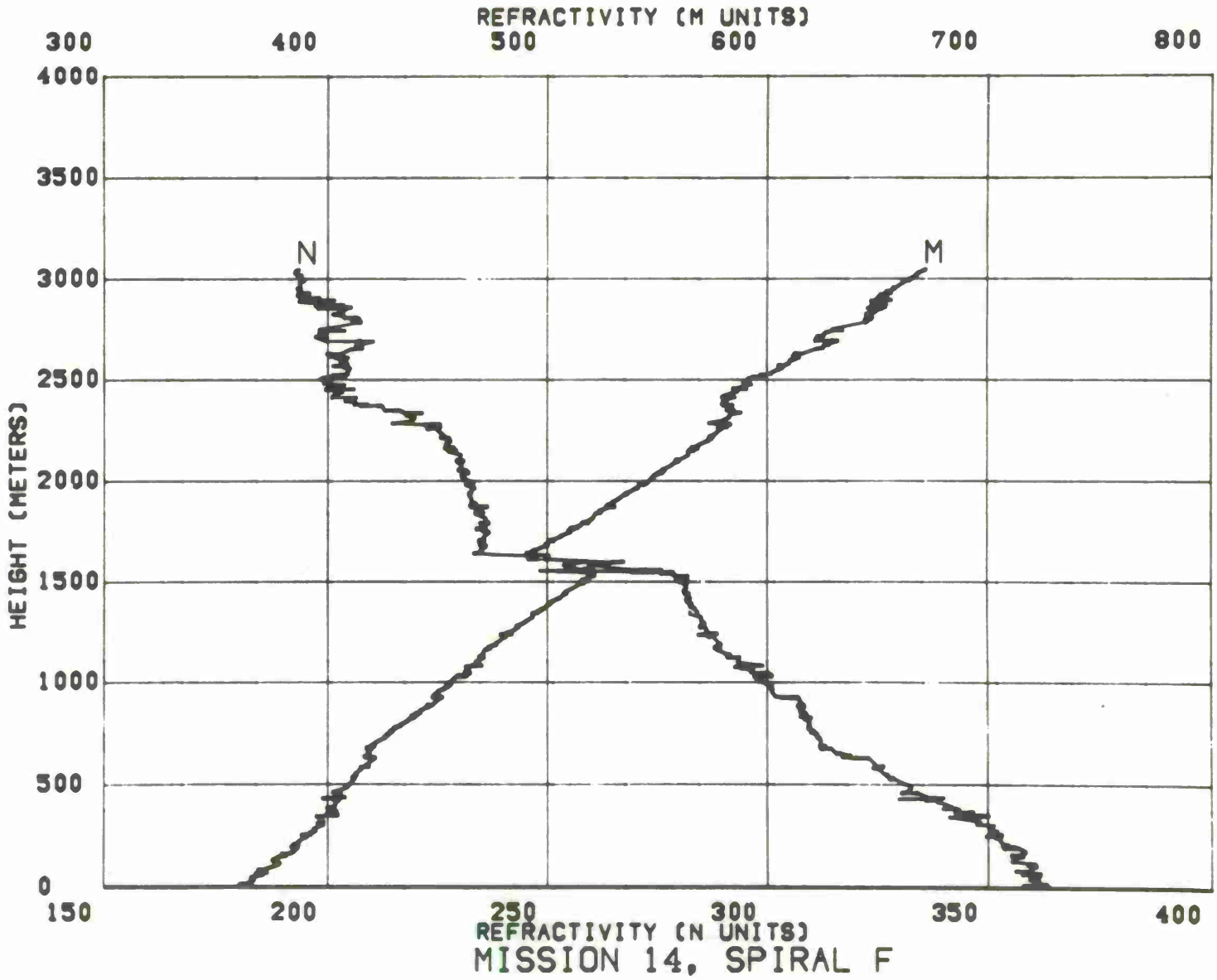
MISSION 14, SPIRAL E



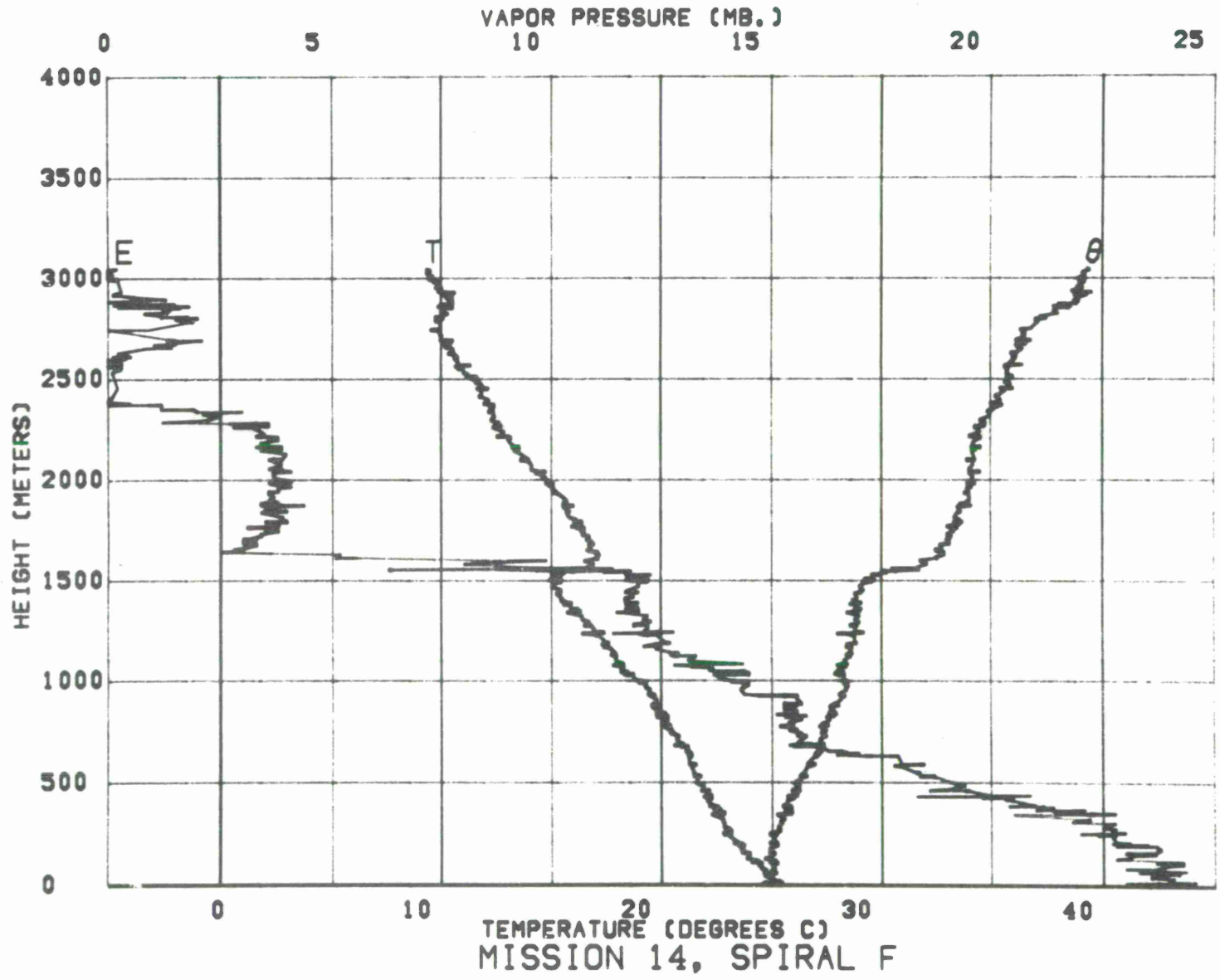
MISSION 14, CLIMB 4



MISSION 14, CLIMB 4



MISSION 14, SPIRAL F



MISSION 14, SPIRAL F

APPENDIX I

A DESCRIPTION OF A C-131 CONVAIR AIRCRAFT USED FOR ATMOSPHERIC RESEARCH

PREFACE

The following paper describes a C-131 Convair flight facility which was instrumented to obtain meteorological and radio refractivity measurements.

The aircraft, under the direction of the Electronics Systems Division, USAF, is used to support radar refraction studies at the National Ranges and also meteorological investigations for Air Force oriented programs.

Having been completely associated with this facility during and since its inception, my intention herein is to provide a reasonably detailed description of the aircraft's capabilities, its past activities, and to indicate its future potential.

Lyall G. Rowlandson

A DESCRIPTION OF A C-131 CONVAIR AIRCRAFT USED FOR ATMOSPHERIC RESEARCH

1.0 INTRODUCTION

A USAF C-131 Convair (37812), based at L. G. Hanscom Field, Bedford, Massachusetts, was instrumented in 1962 to obtain meteorological measurements associated with radio wave propagation. Figure I shows a photograph of the aircraft in flight. To determine propagation characteristics, the fundamental parameter to be measured was the radio refractive index[1,2,3]. However, to obtain accurate measurements it became necessary to also monitor the characteristics of associated air temperature, pressure, and relative humidity. Since these measurements can be in error due to the velocity of the air relative to the sampling probes, the indicated aircraft velocity and air pressure were also required.

The requirement to collect, assimilate and process large quantities of data, together with the requirement to correct the free-air variables due to aircraft motion, led to a digital recording system and an associated data analysis computer program.

The use of the corrected data in propagation analysis requires a knowledge of where the measurements are recorded as a function of time. The facility was, therefore, further modified to include an accurate radar altimeter, 35 mm telescopic camera system and a radio-navigational position.

It is apparent that starting from what initially appeared to be a rather simple requirement led to a much more complicated system. As additional tasks were levied the facility was expanded to include an air sampling system, additional refractometers, tape recorder, accelerometers, drift meter, and radio communications for long over-water operations.

The details of these various instruments and programs will be described later. However, the essential point is that the facility has developed into a flexible and accurate system for investigation of parameter characteristics which affect radio signal propagation. To expand its mission one can think of several additional instruments which are available and which would permit greater involvement in atmospheric measurement programs; namely, a weather-radar, more extensive camera facilities, three directional wind velocity probes (possibly acoustic anemometers) an infra-red camera detection system for water temperature recordings, air particle and aerosol samplers, lyman-alpha humidiometer or dew-point hygrometer, water drop size spectrometer, etc.

FIGURE 1

The primary power and distribution system is adequate to meet these further requirements. Since 1962, the advancements in solid-state development could lead to a considerable power, space and weight saving in much of the existing equipment. Certainly the aircraft is large enough to house additional equipment.

To summarize, the existing aircraft equipment has provided an adequate facility for lower altitude tropospheric propagation and meteorological investigations. Its potential in this important lower region of the atmosphere could be greatly expanded by cooperative efforts of the various atmospheric science investigators to serve a much broader field.

2.0 SPONSORSHIP

The C-131 aircraft is operated by the United States Air Force under the direction of the Air Force Systems Command. It has been based at L. G. Hanscom Field, Bedford, Massachusetts, and was assigned to support technical investigations of the effect of the troposphere on command and control systems. Its experimental flight function was therefore placed under the Electronics Systems Division, Hanscom Field, Bedford. Historically, since 1962, the aircraft has carried out extensive investigations at both the National Ranges (Eastern Test Range, Cape Kennedy, and Western Test Range, Vandenberg, California). Special joint programs have been coordinated with a large cross-section of the scientific community in those areas of investigation where results would have a direct impact on the ESD mission and at the same time, by agreement, the work could be carried out without jeopardizing the open publication of scientific information.

These programs have been extremely fruitful in that the Electronics Systems Division has gained valuable information and support from the scientific agencies affiliated with the programs and, at the same time, the level of competence of the Air Force-Contractor personnel has been greatly improved.

As an example of some types of joint programs, I might mention the radar-backscatter experiments with AFCRL[4], the water-vapor radiometric program with the Department of Meteorology, MIT, the sea-air and anomalous propagation experiments with the Woods Hole Oceanographic Institution[5], the multipath-propagation experiments with the Defense Research Board and the Royal Canadian Air Force [6,7,8], the DCA experiments with RADC, ESSA[9], etc.

The output from these various activities is reflected in the referenced list of publications, not to mention the associated papers which have been and are being prepared for publication in the scientific journals.

It has been a real credit, in my opinion, to the Electronics Systems Division of USAF and to the administering project officers that a reasonable degree of joint scientific effort has been permitted without jeopardizing the direct work to the National Ranges. Otherwise, I believe the program could have become stodgy and limited and the effective support to ESD in knowledge and technical consultation would have been greatly reduced from what it has been.

3.0 DESCRIPTION OF THE AIRCRAFT INSTRUMENTATION

The following table provides a brief description of the types of instruments which are presently in the aircraft, together with their measurements accuracy and time constants.

In addition to the above instrumentation, serious consideration is being given towards mounting an infra-red radiometer to measure sea surface temperature and a weather radar to measure precipitation characteristics. The engineering aspects of this program have not been discussed in any detail with the Airborne Engineering Laboratories at Hanscom Field.

Figure 2 shows, from the top, the AMQ-8 vortex thermometer, the KS4 aerograph thermometer and relative humidity probe, the University of Texas refractometer cavity and the Rosemont thermometer at the bottom. In Figure 1, the two-cavity, vertical N gradient, refractometer may be seen under the starboard wing tip.

A6933

TABLE I

Instrument	Range	Accuracy	Time Constant
1. Vortex Thermometer	-40° to +40°C	±1/2°C	0.5 sec
2. KS4 Aerograph Thermometer	-40° to +40°C	±1/2°C	0.5 sec
3. Rosemount Platinum Wire Thermometer	-40° to +40°C	±0.1°C	0.01 sec
4. MKS-Pressure Transducer	1015 to 500 mb	±0.3 mb	1 sec
5. Giannini Air Speed Transducer	0 to 300 kts	±0.5 kts	1 sec
6. KS4-Aerograph Relative Humidity	0 to 100%	5%	1 sec
7. University of Texas Refractometer-N	0 to 400 N	±0.5 N	0.1 sec (-3 db)
8. Radar Altimeter	0 to 20,000 ft	±20 ft	0.1 sec
9. Master Time-HP Clock		1 in 10^8	0.1 sec (as normally set)
10. Vertical Acceleration - Strathan	±1.5 g	±0.1 g	0.05 sec
11. Flight Research 35 mm Camera on A28 Gyro Mount	0-20,000 ft	±50 ft	1/16 sec
EQUIPMENT ENGINEERED BUT NOT INSTALLED			
12. CEC Dewpoint Hygrometer	(Not tested in Aircraft System.)		
13. University of Texas Refractometers - pod mounted	Designed to measure N gradient over 1 meter in vertical. Test flown but further modifications required.		

FIGURE 2

4.0 RECORDING SYSTEMS AND DATA OUTPUTS

Three recording systems are used on the aircraft:

1. A 36-channel CEC galvanometer, paper chart, recorder.
2. A 16-channel Ampex, FM-analog tape recorder.
3. A special purpose punched-paper tape digital recorder.

The prime data channels, 1 through 9, Section 3.0, are recorded on all systems. The CEC chart recorder has a real-time developing unit which permits the in-flight operation of these instruments to be monitored.

The magnetic tape records of the raw analog data are extremely useful to obtain fine-structure and to plot strip chart or X-Y plots for later playback analysis. Spectrum analysis has been carried out to a limited degree.

The digital recorder can accept up to 14 channels of information every two seconds or can be used on decreased sampling rates. The data are recorded in standard BCD code, making it very compatible for computer processing.

Figure 3 shows an example of the X-Y magnetic tape records of the variation of radio refractivity, N, with height. The aircraft is generally moving in upward or downward spirals at a 500 foot/minute rate. The horizontal thickness on parts of the record is produced by the horizontal variations of N as the aircraft orbits about the vertical axis.

The raw digital data obtained in punched paper tape are packed on magnetic tape for direct input to special purpose computer programs. Table II shows a sample printout from the computer. The first four sets of data are shown, the first group representing the uncorrected free air variables. Looking at the second to last column it is apparent that data were recorded every two seconds.

In this particular test the platinum wire thermometer was not required and was not calibrated or used directly during the flight. The aerograph and vortex thermometer were used and due to the effect of air speed the aerograph readings are greater than the vortex thermometer which is relatively unaffected by speed. The relative humidity was high and in such a case the carbon element in the KS4 aerograph probe can indicate 100% even though the relative humidity may be several percentages less. The radio refractivity, N, together with its variation from a calibration level (delta N) also shows that the relative humidity was very high. The last column is showing a manually induced event, number 3. A variety of event numbers can be indicated, each of which has

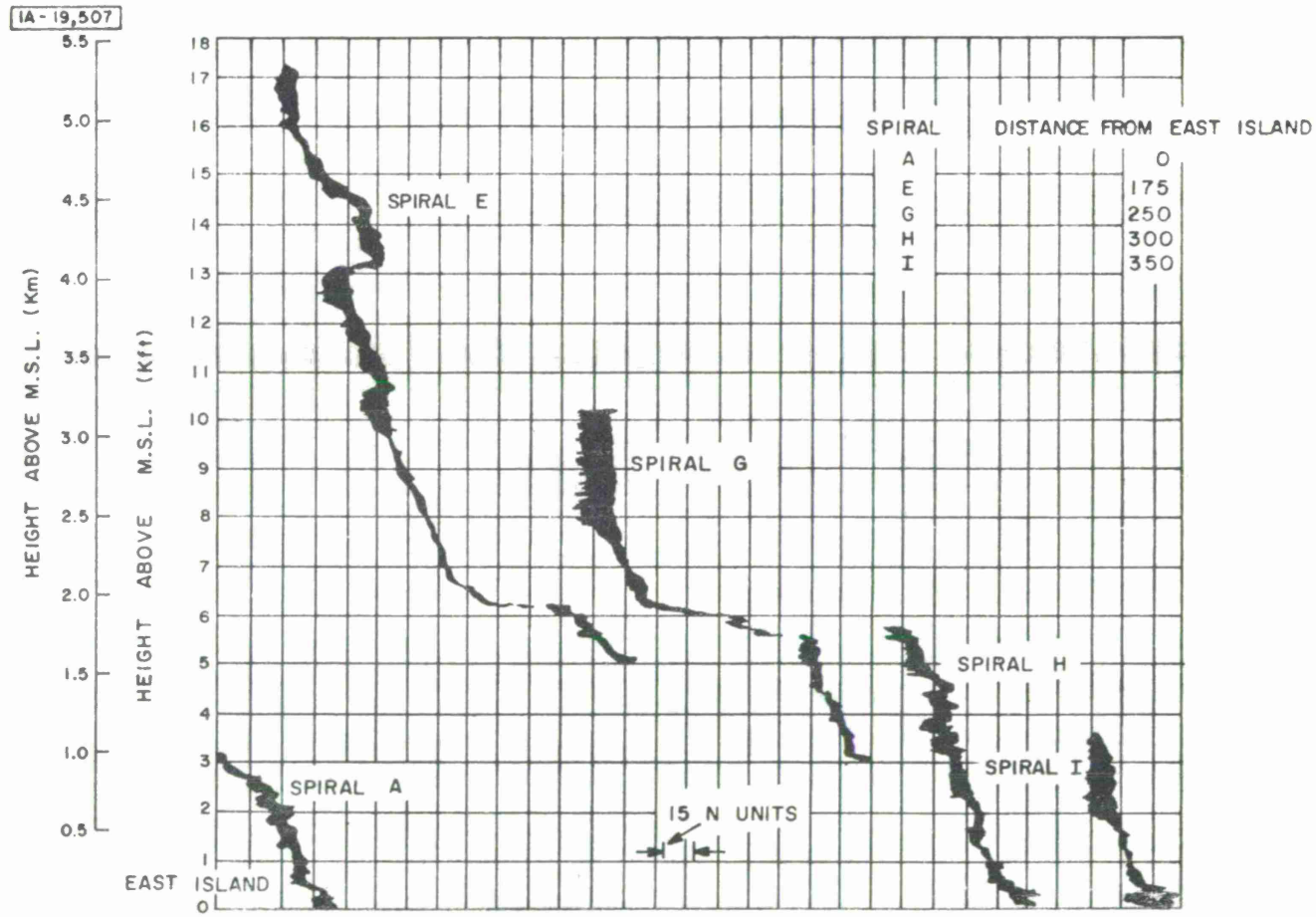


Figure 3. .RELATIVE RADIO REFRACTIVITY PROFILE
9, DECEMBER, 1965 11:00 – 13:45 SAN JUAN LOCAL TIME

TABLE II

SAMPLES OF COMPUTER PRINTOUTS OF PROCESSED AIRCRAFT DIGITAL DATA

INPUT DATA FOR THE COMPUTATION OF FREE AIR VARIABLES
FOR AIRCRAFT FLIGHT - SAN JUAN MISSION NO. 401, 7 DECEMBER 1965

Reading	Indicated Airspeed Knots	Pressure MB	Aerograph Deg. C	Temperature Plat. Wire Deg. C	Vortex Deg. C	Humidity Carbon S Percent	Refractometer Delta N	Refractometer N	Altimeter Meters	Time	Event
1	156.3	916.6	21.2	-17.7	19.2	100	56.3	321.7	870.9	70440	3
2	155.3	915.1	21.6	-17.6	19.4	100	60.0	318.0	861.9	70442	3
3	154.7	916.1	21.4	-17.6	19.5	100	57.1	320.9	861.9	70444	3
4	153.7	916.6	20.8	-17.7	20.2	100	53.9	324.1	858.9	70446	0

FREE AIR VARIABLES COMPUTED FOR AIRCRAFT FLIGHT
SAN JUAN MISSION NO. 401, 7 DECEMBER 1965

Reading	Pressure MB	Aerograph Deg. C	Temperature Plat. Wire Deg. C	Vortex Deg. C	Aerograph Pot. Temp Deg. C	Aerograph N Dry	Aerograph Pot. Temp Deg. C	Aerograph N Dry	Aerograph Mixing R G/KG	Aerograph N Wet	Aerograph N	Refractometer + Aerograph Mixing R G/KG	Refractometer + Aerograph N Wet	Refractometer + Aerograph N
1	917.6	19.2	-16.3	19.7	26.5	243.6	26.5	243.6	17.11	107.2	350.8	12.16	76.8	320.4
2	916.1	19.6	-16.2	19.9	27.0	242.9	27.0	242.9	17.58	109.6	352.5	11.74	73.9	316.8
3	917.1	19.4	-16.2	20.0	26.7	243.3	26.7	243.3	17.34	108.4	351.7	12.11	76.8	319.8
4	917.6	18.8	-16.3	20.7	26.2	243.9	26.2	243.9	16.70	105.0	348.8	12.49	79.0	322.9

REFRACTIVE INDEX PROFILE FOR AIRCRAFT SPIRAL
SAN JUAN MISSION NO. 401, 7 DECEMBER 1965

Reading	N	Height Meters	M	Potential Temp. Deg. C	Refractometer + Aerograph Mixing Ratio G/KG	Refractometer + Aerograph Pressure MB	Refractometer + Aerograph Vapor Pressure
1	320.4	914.0	43829.0	26.5	12.16	917.6	17.60
2	316.8	927.8	45992.7	27.0	11.74	916.1	16.98
3	319.6	918.6	44549.7	26.7	12.11	917.1	17.52
4	322.9	914.0	43831.7	26.2	12.49	917.6	18.06

some particular significance to the mission. In this case, event 3 means "beginning downward spiral" obviously from an altitude of 870 meters above mean sea level.

The second group again shows some of the initial free-air variables but which have now been corrected in the computer program to take account of aircraft speed and altitude. The agreement between the aerograph and vortex readings is now much better. The air pressure reading has also been adjusted by 1 millibar from its original uncorrected value.

The computer next calculates the potential air temperature, θ [10], the dry term of the index of refraction, N_d, based on the corrected air temperature and pressure readings. The fact that these data are repeated twice, under the heading aerograph, indicates that these calculations were based on the aerograph thermometer measurements. Of course, any one of the three thermometers may be selected.

The next column shows the mixing ratio [10], wet term of the radio refractivity, N_w, and the total, N, calculated from the aerograph thermometer, the aerograph relative humidity probe (carbon strip) and the air pressure records. Using the Smith-Weintraub equation [3] for the radio refractivity, N, the water vapor pressure, e [10], and therefore the mixing ratio, r, can be calculated since the air temperature, air pressure and refractometer-measured value for N are known.

The aerograph calculations show a greater value for the mixing ratio and the N term due to the fact the carbon strip indicated saturation, whereas the refractometer indicated below saturation conditions.

The last column shows the corrected total value for N using the refractometer but where aerograph thermometer readings were used to correct the thermal expansion of the refractometer cavity. Calibration of the flight facility shows that water vapor calculations are much more accurate using the refractometer data than with the aerograph, providing precipitable water is not present within the refractometer cavity.

The final printout provides a selection of parameters which have been used to the greatest extent in radio propagation studies. The first is, of course, the corrected radio refractivity, N, and the geopotential aircraft altitude, h [10]. A subsequent modification in the program permits the radar altimeter measurement to be printed out adjacent to the geopotential height column. Over water, these radar measurements are extremely useful. The modified index, M [11], is derived from N, the aircraft height, h, and an earth radius factor. It is of

special interest in ray tracing analysis[11]. The remaining columns show the potential air temperature, θ, mixing ratio, r, (using corrected refractometer data) the air pressure, P, and the water vapor pressure, e [10](obtained directly from the Smith-Weintraub equation).

5.0 FURTHER ANALYSES USING THE RADIO-METEOROLOGICAL DATA

There are, of course, many ways in which the processed data may be used. For radio wave propagation, the most important information is the behavior of the radio refractivity, N, in both its vertical and horizontal dimension.

The preceding N data, together with height, can first of all be used to define the vertical variation of N and its effect on radar tracking errors. For example, the following tables show a comparison of errors using two N profiles, the first obtained with the aircraft and the second obtained from a radiosonde.

In Table III, a typical set of results are determined for a radio ray initiated at a point 60.4 feet above the earth's surface, at an initial elevation angle of 18 mr, and terminating at four different stop heights. The profile N(h) was derived from a particular aircraft sounding in the local area beginning at 2018 hours.

From the results of the ray tracing analyses the electrical ranges are first calculated and then the range error produced by retardation of the velocity of propagation along the path (and, of course, due to the N values) relative to the true geometric path. See Figure 4 for an illustration of the parameters under consideration.

The next column shows the total amount of ray bending which took place and the resulting elevation angle error, E. The next column shows a k value which when multiplied by the true earth's radius gives an effective earth's radius, A_e. This effective radius represents an enlarged earth over which one may consider the radio waves to travel in straight lines [11].

In Table IV the preceding results obtained with the aircraft measurements are compared with a particular radiosonde sounding. The differences may appear to be small but in many applications where very accurate tracking accuracy is required the results can indicate that radiosonde data are not sufficiently detailed to describe the propagation conditions.

Similarly with greater difficulty, analyses can be carried out using both the vertical and horizontal characteristics of radio refractivity. In this case aircraft measurements would be required in both the vertical and horizontal directions [12].

TABLE III

CALCULATION OF REFRACTION EFFECTS

h_2	Range R (nm)	Range Error $(R-R_o)$ ft.	Total Bending τ(mr)	Elevation Angle Error ϵ (mr)	k	Effective Earth's Radius A_e (nm)
8750.0	58.135	98.84984	3.8869643	1.8508379	1.282458	4406.11
8800.0	58.400	99.21361	3.9110985	1.8601380	1.282619	4406.69
8850.0	58.665	99.57561	3.9351915	1.8694472	1.282783	4407.27
8950.0	58.901	100.29431	3.9832550	1.8880917	1.283120	4408.47

$n(h)$ = Profile I (A/C Sounding Primrose 2018 hours)

h_1 = 60.4 feet

θ_o = 18.0 mr

h_2 = Nominal A/C Pressure Altitude, 8850 feet (Cold Lake)

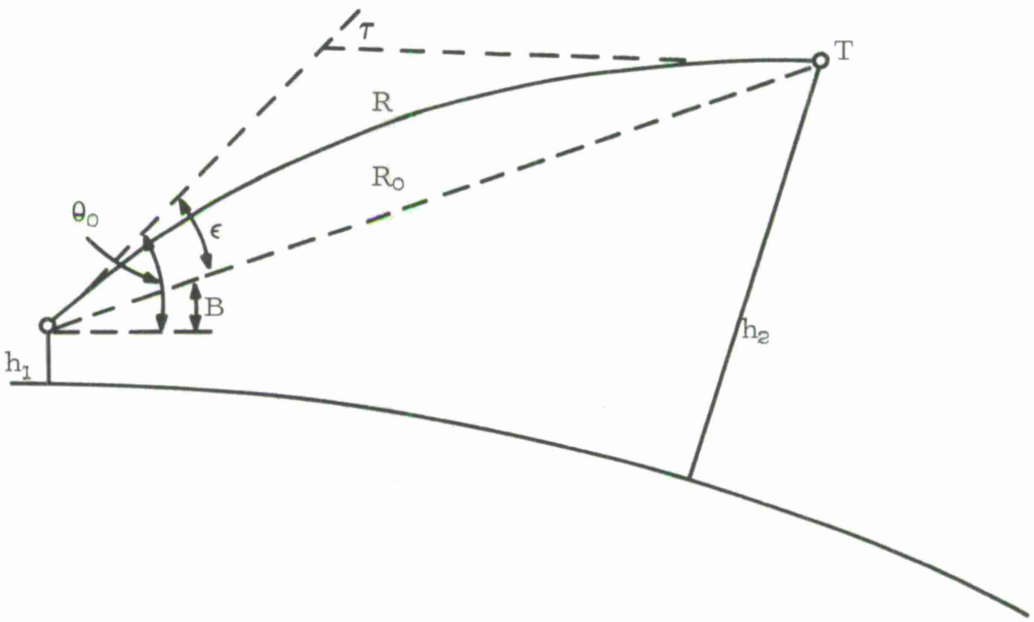


FIGURE 4. RAY-TRACING GEOMETRY

TABLE IV

COMPARISON OF REFRACTION VARIABLES FOR TWO PROFILES

h_2	Range Difference (nm)	Range Error Difference ft.	τ Difference	ϵ Difference	k Difference	(kft) A_e Difference
8750.0	-3.194377	1.510333	-0.424719	-0.296876	-0.056308	177.816468
8800.0	-3.208281	1.519930	-0.412768	-0.297425	-0.056154	174.597458
8850.0	-3.221475	1.529104	-0.400832	-0.297911	-0.055990	171.164189
8900.0	-3.233967	1.537854	-0.388911	-0.298333	-0.055816	167.524125
8950.0	-3.245766	1.546181	-0.377005	-0.298695	-0.055633	163.684481

Profile I = A/C Sounding - Primrose 2018 hours.

Profile II = Radiosonde Sounding - Primrose 2018 hours.

h_1 = 60.4 feet.

θ_0 = 18.0 mr.

h_2 = Nominal A/C Pressure Altitude, 8850 feet (Cold Lake).

In the evaluation of radiometer systems, the line integral of water vapor and temperature are of most direct interest but the ray tracing data are still required to determine the path of the signal. For examination of anomalous propagation conditions the vertical gradient of the radio refractivity is of greatest interest and potential air temperature correspondingly of greatest interest in atmospheric stability analyses [11].

It is apparent that the basic aircraft data can be used in a wide range of interconnected subjects. Also, the addition of a few pieces of selected equipment could greatly enhance the potential of the facility in the areas of sea-air interaction, air polution and aerosol characteristics, rainfall distributions (water reclamation), and weather modification programs.

6.0 SUMMARY

References to the detailed data reduction and ray tracing programs have not been given since these are of little general interest. The essential intention was to indicate the direct airborne measurement capability of this aircraft and to suggest the potential it could have for other expanded areas of investigation in the lower troposphere.

The ray tracing and data reduction analysis were discussed in considerable detail mainly because they are interrelated and represent the important output in most radio propagation experiments.

Finally, the problem of obtaining accurate data with a fast-moving airborne platform is formidable and possibly was not given sufficient attention. This subject was again considered to be of little general interest in spite of the fact that it is an extremely important and difficult area.

The development of the two sensing cavity refractometers to measure the vertical N gradient has been frustrated due to the aircraft's electrical noise generated on long lines passing through the wing and to microphonics associated with the active RF elements. However, recent measurements indicate that it appears possible to measure 0.1 N units variation between the 1 meter vertically separated cavities. New, open cavities are being developed in order to improve the frequency response of the whole system [13].

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13. ABSTRACT

A series of meteorological measurements was made in the northern part of the Caribbean Sea during the spring of 1969, to characterize the Trade Wind Inversion and its effect on radio wave propagation. Among the measurements made were data collected from the sensors on the airborne platform of the USAF C-131 Convair (37812), which was provided for use on this contract. This report is a compendium of some of the airborne data, namely of the processed digital records of air temperature, air pressure, refractivity, water vapor pressure and potential temperature. These values are presumed as absolute quantities which have been corrected to compensate for the effect of aircraft motion and thermal expansion of the microwave refractometer sensing cavity.

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